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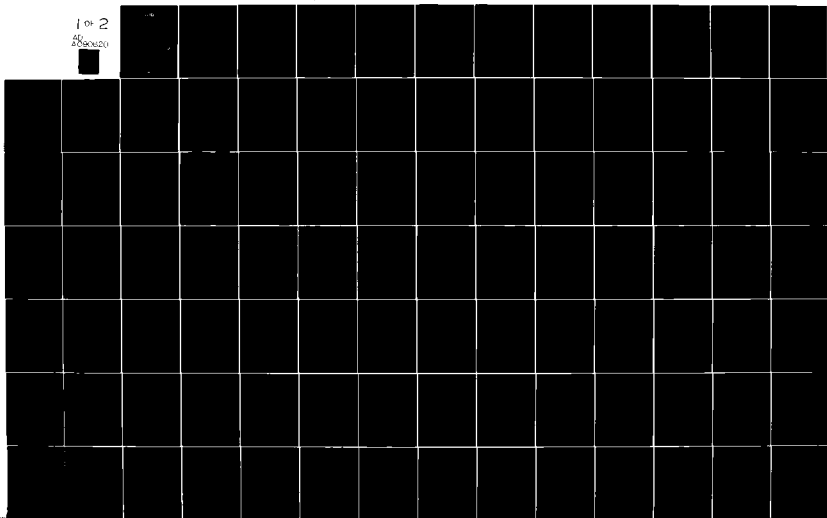
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LEVEL II

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NORTHWESTERN UNIVERSITY

⑥ ANALYSIS OF THE  
CONNECTIVITY AND CENTRALIZATION  
OF REGIONAL AIR FREIGHT NETWORKS.

⑦ Master's THESIS,  
SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

⑭  
AFIT-CI-79-169T

For the Degree

MASTER OF SCIENCE

Field of Transportation

By

⑩ PETER W. RUSSO

Evanston, Illinois

⑪ Aug 1978

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CHAPTER I  
INTRODUCTION

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1. Development of the Industry.

Although components of the air freight industry have been in operation since the start of commercial aviation, it is only in the last decade that its continued rapid expansion has given the industry credence as a freight transportation mode. In this decade, freight ton miles by air have grown somewhat erratically, but at an average rate of about 8% per year. Figure 1-1<sup>1</sup> traces this development, and shows that the United States currently produces about 40% of these ton miles, and reaps a similar percentage of the revenues.

The five billion revenue ton miles which U.S. air freight carriers hauled in 1977 represents only 0.2% of the total domestic intercity freight. However, in 1976, air freight produced revenues of \$2.052 billion,<sup>2</sup> which was 1.2% of the nation's total freight bill, \$165.2 billion. Obviously, the threat of air freight as a competitor lies not in volume, but in its ability to skim high revenue-producing traffic from surface modes.

The growth of the U.S. airline and air freight industry has been affected to a great extent by U.S. regulatory policies. These policies stem mostly from the Civil Aeronautics Board (CAB), which is charged by the Federal Aviation Act of

## TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES.....	iii
LIST OF TABLES.....	iv
 <u>Chapter</u>	
I        INTRODUCTION.....	1
1.    Development of the Industry.....	1
2.    Pressures for Deregulation.....	4
3.    Thesis Motivation.....	5
4.    Thesis Plan.....	7
II        AIR FREIGHT ECONOMICS AND LITERATURE REVIEW..	10
1.    The Economics of the Air Freight Industry.....	10
2.    Literature Review.....	26
III       MODEL DEVELOPMENT.....	31
1.    Overview.....	31
2.    Quadratic Programming Model.....	37
3.    Route Generator.....	44
4.    Simulation of an Air Freight Terminal....	46
5.    Experimentation.....	49
IV        RESULTS AND CONCLUSIONS.....	57
FOOTNOTES.....	72
BIBLIOGRAPHY.....	76
APPENDIX I -- QUADRATIC PROGRAM.....	80
APPENDIX II -- FORTRAN ROUTE GENERATOR.....	85
APPENDIX III -- SIMULATION.....	95

## LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1-1	Air Freight and Traffic Revenues.....	2
2-1	Distribution of System Cost by Cost Element...	21
2-2	Comparative System Transport Costs.....	24
3-1	Model Flow Chart.....	32
3-2	Network Plan View.....	34
3-3	Network Expanded View.....	34
3-4	Simulation Cost Curve.....	50
3-5	Hypothetical Base Network.....	53
3-6	Experimental Networks.....	54
4-1	Network Flows Resulting From Experiments.....	62

# LIST OF TABLES

<u>Table</u>		<u>Page</u>
II-1	COMPARATIVE OPERATING RATIOS.....	14
II-2	COMPARATIVE CAPITAL PRODUCTIVITY.....	15
II-3	IMPACT OF DENSITY ON OPERATING COSTS.....	18
II-4	AIRCRAFT UTILIZATION AND LOAD FACTORS.....	19
III-1	ASSUMED PARAMETER VALUES FOR AIRCRAFT LOAD AND COST.....	36
III-2	DEFINITION OF QUADRATIC PROGRAM TERMS.....	38
III-3	SUMMARY OF AIRCRAFT AND TRUCK CHARACTERISTICS.	52
IV-1	TABLEAU OF EXPERIMENTAL RESULTS.....	61

## CHAPTER I

### INTRODUCTION

#### 1. Development of the Industry.

Although components of the air freight industry have been in operation since the start of commercial aviation, it is only in the last decade that its continued rapid expansion has given the industry credence as a freight transportation mode. In this decade, freight ton miles by air have grown somewhat erratically, but at an average rate of about 8% per year. Figure 1-1<sup>1</sup> traces this development, and shows that the United States currently produces about 40% of these ton miles, and reaps a similar percentage of the revenues.

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The growth of the U.S. airline and air freight industry has been affected to a great extent by U.S. regulatory policies. These policies stem mostly from the Civil Aeronautics Board (CAB), which is charged by the Federal Aviation Act of



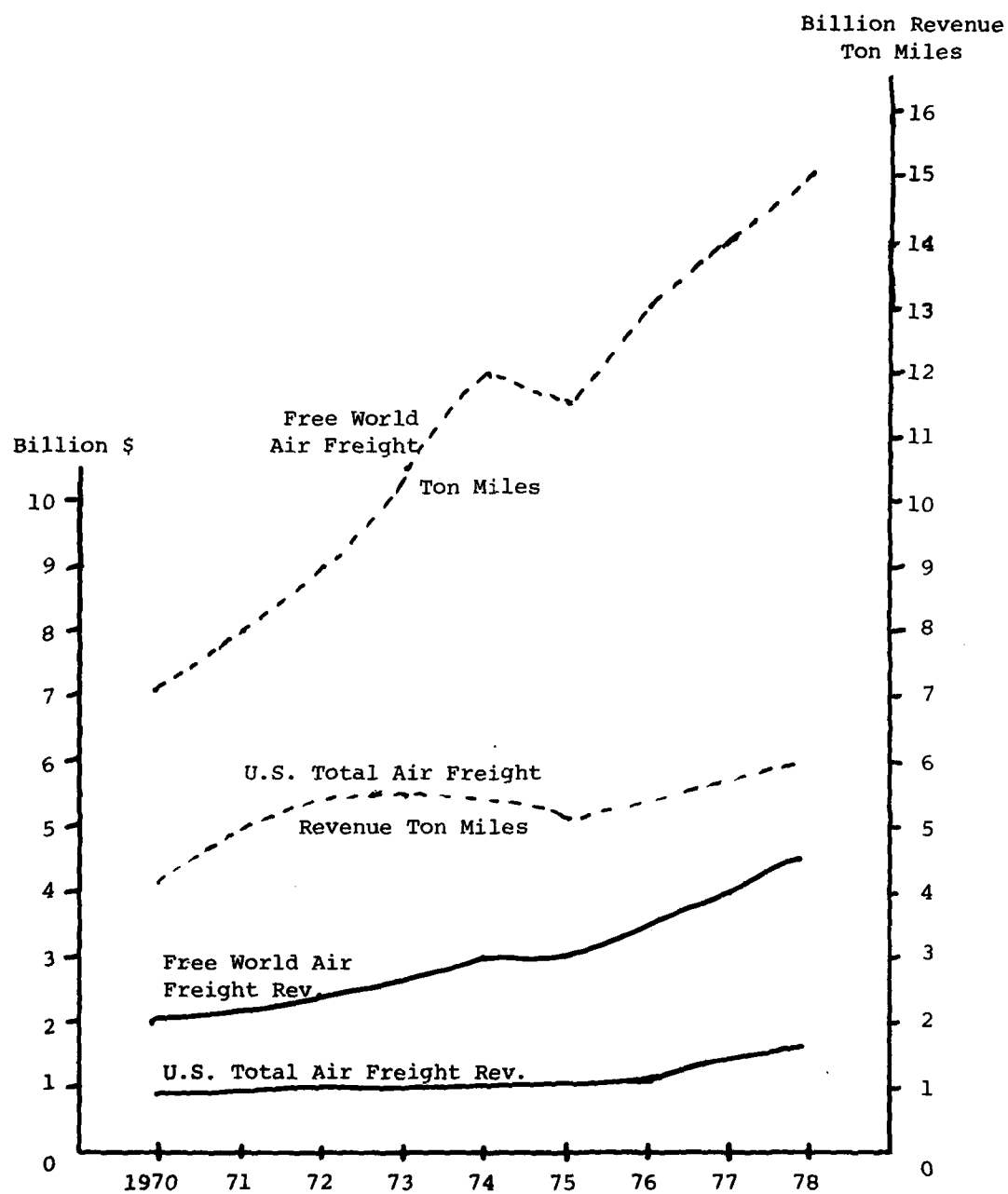


Figure 1-1. Air Freight Traffic and Revenues.

Source: Aviation Week & Space Technology,  
13 March 1978.

1958 both to regulate and promote the industry. Historically, this regulation and promotion differs from that of other modes in that it was planned as such from the start (1938) and did not evolve from pressure by other regulated modes, or by shippers. The objectives of such a comprehensive program of support for the air industry have been summarized by Caves:<sup>3</sup>

- 1) military advantages of planes and the facilities to build them,
- 2) a network of routes provided by the public for use by all,
- 3) a strong airplane industry to speed new developments in aircraft,
- 4) stability in the industry, which encourages safety, and
- 5) economic regulation which stabilizes rates and restricts unfair price discrimination.

CAB regulation has tended to be quite protective of airline industry interests. Sixteen trunk carriers received CAB certificates in 1938, and not another entry into that category has taken place since. Recognition of other types of service was usually resisted by the CAB, which was the only source of interstate certificates. Local service was recognized in 1943, while "irregular" non-certified carriers were permitted in 1947. In 1949, faced with hundreds of uncertified cargo carriers, many of dubious financial stability, the CAB licensed four all-cargo carriers. Federal subsidies were also being administered to trunks and local carriers, through the award of lucrative mail contracts. The economic regulation as exemplified by subsidies, rate regulation, and route and entry restrictions resulted in a growing air industry. By 1959, the last of the trunk lines had become

wealthy enough to come off the subsidy.

## 2. Pressures for Deregulation.

In the early sixties, an increasing number of economists and industry analysts presented arguments that perhaps the CAB's policies had served their purpose and were now more restrictive of growth and economic efficiency. Pegrum characterized the CAB's ratemaking policy as thirty years of indecision.<sup>4</sup> In surveys comparing regulated and unregulated carriers in California, Jordan estimated that unregulated lines could, and do, charge 32 to 47% lower fares for the same service.<sup>5</sup> Keeler puts the overcharge at 20 to 95% above economic costs for short and long haul flights, respectively.<sup>6</sup> In two sets of Senate hearings in 1975 and 1977, a great number of independent economists presented cogent arguments in favor of deregulation.<sup>7</sup> Perhaps the greatest force for rationalization of the industry has been the presence of A. Kahn as Chairman of the CAB. This noted economist has been an outspoken critic of past CAB regulation and has campaigned for a gradual phaseout of these economic regulations.<sup>8</sup>

The first step toward this goal was taken in November, 1977, when President Carter signed into law a bill to deregulate air cargo carriage. All route, entry, and rate restrictions are removed from CAB control, except for carrier actions which it deems preferential, prejudicial, predatory or discriminatory. New carriers may enter the industry after November, 1978, and must still be certified by the CAB. Non-economic controls, such as equipment standards, pilot

licensing, etc., were not affected. Concurrently, Chairman Kahn has begun a policy of approving large passenger fare reductions and route changes, thus extending the route and rate rationalization, or tendency toward market equilibrium, into the passenger sector.

### 3. Thesis Motivation.

There is a significant difference of opinion among analysts as to what the long run effects of this rationalization will be. In the discussion of the economics of air freight in Chapter II, the stands taken by various interested parties will be analyzed. It appears that if cargo and passenger route and entry rationalization produces the forecast cost savings, a significant expansion of capacity may take place. Rates will fall to attract more passengers and cargo. The implications for the cargo carriers seem to be that they will have to provide service at a lower cost. Since it will be shown later that a large portion of these costs is related to ground transport and handling procedures, the effort to minimize costs should be made on a system basis. This will create at least three needs:

- 1) To improve service, especially in the air cargo market, to attract the cargo volume required.
- 2) To optimize further the performance of the system as a whole, including ground transport, transshipment to air, and air transport, in order to reduce carrier costs.

- 3) To reassess current route networks and transfer points in light of the increased volume and associated congestion and delays.

This thesis deals primarily with need number two. The objective is to discover how air freight will move from several sources within a region to its final destination outside the source region. By setting up a series of source nodes, connecting them to airport terminals by truck routes, then connecting these airports with local air freight links, as well as to the final destination by long range air freight links, we have a facsimile of the air and ground options available for routing cargo. By applying impedances to these links, such as truck and air costs and terminal costs, each time the cargo changes vehicles, the flow of cargo can be found which minimizes the cost of this operation. Finally, by experimenting with different sized and shaped networks, generalizations can be made which can help to satisfy need number two above.

This does not imply that a deregulated system will operate as a global cost minimizer. On the contrary, with many individual profit maximizers participating in each phase of transport, the free-market equilibrium flows may not resemble the optimal flows described here at all. However, this work does have value in describing the hypothetical, optimum cargo routing. By comparing the actual flows to these movements, an observer would be able to identify areas of relative sub-optimization. Also, in cases where a central system

planner does exist, such as in private or military logistics moves, he may indeed be able to aim for a global system optimum.

The results of these experiments can be of value to several parties:

- 1) Airport and terminal planners, when modifying or constructing facilities, will need to know how much cargo their changes will attract.
- 2) Air carriers must be able to assess the implications of route additions or deletions on the system, and, ultimately, how much cargo will their routes carry.
- 3) Forwarders and private carriers who deliver most of the freight to air terminals must be able to route cargo to the airport terminal which, in conjunction with air schedules, will produce the least cost transit out of the region.
- 4) Even shippers who plan to depend heavily on air freight can assess alternative location strategies in light of system cost effectiveness, although this may not be the cost he will see reflected in his rates.

#### 4. Thesis Plan.

The remaining three chapters of this thesis will cover an economic description of the air freight industry and a literature review, the development and use of the model, and conclusions to be drawn from the experiments conducted.

The economics section will describe the components of

the air freight industry, the resources it uses, and the needs it satisfies. To optimize such a system has implications for each of these topics, and these will be discussed also. The literature review will cover some of the work done in each of the major areas of this thesis: economic analysis of air freight, simulation models of air cargo terminals, and math programming models of air networks.

Chapter III will describe the hypothetical network we will be concerned with, as well as present an overview of how the various model segments blend together to describe the network. The first phase of the model is a mathematical program, which is a linear program in all respects but one: one term in the objective function is quadratic. This variable describes the costs of moving tonnage through an air freight terminal. This quadratic program minimizes total costs, which include truck transport costs from city to airport, terminal costs, and airplane routing costs. Since many aircraft routes must be examined to allow a wide choice so as not to exclude optimal possibilities, the job of listing these routes, and restricting the number considered to a smaller sample is the purpose of the Fortran Route Generator. This second phase computes each route's cost, hours flown, and points served given network size and shape. The elimination of routes is based on aircraft range and utilization limits. The third and final phase consists of a computer simulation of an air cargo terminal. The result of this model is a quadratic total cost function for tonnage transshipped

through the terminal. This function becomes the quadratic term in the math program's objective function. The final section of this chapter will describe the specific experiments to be carried out on the network.

Chapter IV will describe the results of these experiments and attempt to draw general conclusions which relate the network characteristics to the ultimate optimal flow. -- At this point, it will be shown that due to several unexpected problems, it was no longer feasible to conduct this analysis using quadratic programming techniques. The mathematical program was reduced to a completely linear model, and the system was redesigned with a linear term representing terminal costs. Because the circumstances which forced this change are peculiar to the choice of quadratic programming packages and computer size limitation, they can be overcome. Therefore, this section of the model will be referred to as a quadratic program to describe its intended use.

A detailed description of the results of each experiment is then presented. Some generalizations will be made regarding air freight network optimization, and recommendations to industry participants will be made, based on these findings. Finally, a brief summary will be presented.



## CHAPTER II

### AIR FREIGHT ECONOMICS AND LITERATURE REVIEW

#### 1. The Economics of the Air Freight Industry.

a. Composition. This section will describe the components of the air freight industry, the characteristics of the resources used, the influence of government regulation, and the economic implications of these factors. The pertinent literature will be cited here to avoid repetition in the next section, the thesis literature review.

Air freight is a term usually applied to one type of cargo carried on aircraft. Air mail and air express (small packages) are two other types, which when consolidated into larger loads, may enter the air freight category. The participants in the air freight system are basically the shippers, the surface carriers, and the air carriers. Air freight forwarders are "indirect carriers" certified by the CAB to carry air cargo, but not permitted to operate aircraft. Actually the forwarders are a combination of all three components: to the shipper, the forwarder is a surface and air carrier; to the air carrier, the forwarder tenders goods for shipment at the same rates as do shippers; and, finally, forwarders can charter planes and serve as their own air carriers.

Smith presents a detailed description of this international industry in Air Freight Operations, Economics, and

Marketing.<sup>1</sup> Schneider concentrates on the management aspects of the domestic air freight industry.<sup>2</sup> Forwarders play a vital role in providing more reliable service in this highly service-oriented industry. In 1973, domestic forwarders tendered 816,000 tons of freight to the domestic airlines, and in terms of sales 41% of the carriers' total air freight revenue was forwarder-generated. For the domestic all-cargo carriers, the share was even greater, 51%. These figures are taken from what is probably the most comprehensive analysis of the air freight forwarding industry to date, the Ph.D. dissertation of Stephenson, An Analysis and Evaluation of the Domestic Air Freight Forwarding Industry.<sup>3</sup>

b. Shippers. Early research to analyze the shippers' demand for air freight was conducted by Allen and Moses,<sup>4</sup> who proposed the use of ordinary regression analysis to estimate the demand for sea vs. air transport across the North Atlantic. The equation concentrated on maximizing shipper profit, which was determined by production costs, revenues, transport costs, and a present value cost of time in transit. Expanding on this concept, Stephenson's extensive shipper surveys presented strong evidence that shipper demand for air freight stems from the services offered by air freight forwarders and carriers (speed, reliability, service flexibility) rather than cost concerns.

An often heard complaint within the industry is that demand has tended to be more for emergency shipments rather than routine cargo. Although the actual percentage of air

freight which is emergency shipments is unknown (estimates run from 25 to 75%), it is apparent that the nature of the freight (little advance notice, emphasis on speed, usually small size) requires the highest degree of system responsiveness and incurs the highest costs. Recently, emphasis has been placed on the "total distribution approach" where air freight is offered as a routine method of delivery. Naturally this type of analysis depends on the tradeoff between the premium transportation charges associated with air freight and surface expenses of the standard distribution system. Inputs to such analysis include: warehousing costs, the warehouse replenishment order quantity, the order point at which time a replenishment is initiated, the level of safety stock to protect against variability of demand and lead time, the value of the product, and inventory carrying, communications, and order processing costs. Schneider<sup>5</sup> offers a complete example of such an analysis. Several articles offer further enlightenment on the relation of air freight to the total distribution system. They include works by Fletcher,<sup>6</sup> Lineaweaver,<sup>7</sup> Slater,<sup>8</sup> and in Freight Management.<sup>9,10</sup>

c. Carriers. All air freight shipments are of necessity intermodal, and the vast majority of them are hauled locally by truck and line-hauled by air. The intermodal transfer is accomplished at air cargo terminals, which represents a significant cost and time delay to the shipment. Stites found that ground operations costs can be twice as important to cargo profits as airplane initial costs.<sup>11</sup>

Terminal cost analysis is the subject of the simulation described in Chapter III, Section 4.

Air and truck freight carriers are similar in many respects; both operate comparatively (to rail and water) small vehicles. These vehicles travel on systems which are publicly owned and maintained, but at least partially paid for by taxes on the carriers. Both use a combination of private and public terminals to load and unload. Economically, both industries depend on maintaining a high load factor in their vehicles for their profits; however, for an air carrier, filling the vehicle involves somewhat more than it does for a truck carrier. This will be discussed below.

High vehicle and equipment costs, or high capitalization, is the characteristic which best contrasts air carriers with trucks. This means that fixed costs are a high percentage of air costs, while they are minimal for trucks. Table II-1 compares the average operating ratio of the pure freighter aircraft of four major air carriers with that of rail and motor carriers. Operating ratios are calculated by dividing operating expenses before interest and taxes by operating revenue. Notice that the cost of operating pure freighters has at times exceeded the revenue produced, resulting in a net operating loss for these aircraft. The rail and truck figures do not adequately reflect a comparison of operating policies, as other factors affect these modes. Motor carriers, for instance, are regulated by the ICC to achieve a set operating ratio.

TABLE II-1

COMPARATIVE OPERATING RATIOS  
RAIL - TRUCK - AIR FREIGHTERS

	High Profit Year	Low Profit Year
U.S. Railroads	.7618 (1966)	.8118 (1970)
Class I & II Motor Carrier	.947 (1965)	.962 (1970)
Air Freight Operations*	.9638 (averaged)	1.147 (averaged)

NOTE: Operating Ratio = Operating Expense / Operating Revenue

SOURCE: Data compiled by L. M. Schneider in "The Future of the U.S. Domestic Air Freight Industry."

\*Air Freight Operations figures are the averages from the freighter operations of American, United, Trans World and Flying Tiger Airlines.

A companion statistic is the rate of capital turnover, or the ratio of revenue to net investment in operating property. These are shown in Table II-2.

It can be seen that freighter operators face high operating ratios similar to those of truckers, but can only achieve the capital productivity similar to railroads. Rate of return information on the pure freighter operations of combination carriers was not available, and these figures for overall operations are distorted by other factors. These overall rates of return reflect the dominance of passenger service, and the airlines are in fact regulated economically

TABLE II-2  
COMPARATIVE CAPITAL PRODUCTIVITY  
TRUCK, RAIL, DOMESTIC AIR FREIGHTER SERVICE  
1969

	A) Operating Revenue	B) Net Investment in Operating Property	Ratio A to B
	(Billions of Dollars)		
Class I & II Truck	7.339	1.670	4.39
Class I Rail	11.451	27.734	.413
Total, Four Airlines	.177	.300	.59

SOURCE: L. M. Schneider in "The Future of the U.S. Domestic Air Freight Industry."

by the CAB to achieve a set rate of return. Historically, carriers have been hard-pressed to show a profit with their freighter operations. For the combination carriers, which fly passenger and combination passenger-freight planes, this has led to a decrease in the number of domestic freighter flights. Carriers which fly only freighters, such as Flying Tiger and Seaboard World, have relied heavily on charters and long haul overseas flights to produce profit. In Europe, with many of the domestic and international routes consisting of relatively short hops, all-cargo freighters have yet to break even. Again, the profit lies in long haul freighter routes, and also in the use of belly compartments of jumbo passenger jets.

d. Resources. It is becoming apparent that a major obstacle to air freight carrier profits is the aircraft. Although the introduction of turbine power reduced costs about 50% below piston and turboprop costs, today's aircraft are still not designed to carry cargo with maximum efficiency.

The major types of aircraft used for heavy freight carriage include wide-body freighters (B-747F), narrow-body freighters (DC-8, B707), and the lower holds of wide-body passenger jets. There are also combination aircraft in which the main deck carries freight forward of the passengers and separated from them by a movable bulkhead. Quick change (QC) aircraft allow the passenger seats and floor to be removed from the aircraft in minutes, to be replaced by cargo rollers and tiedown equipment.

The two crucial variables for a carrier's profitability are the number of revenue ton miles flown and the cost of aircraft operations. In order to maximize profits, he must be concerned with load factor and aircraft utilization. Load factor is the ratio of revenue tons to available tons of capacity. Aircraft utilization is the number of hours flown per day.

Attaining a high load factor is obviously a carrier goal, given a fixed fleet composition, but the carrier will not allow his load factor to rise too high, for this means that the level of service offered to shippers is low. Space will not always be available for last minute shipments, and customers will be lost. However, there exists a break-even load factor,

below which the revenue for the route flown does not exceed the costs of flying it. Two aircraft characteristics which will raise the break-even load factor are its shape and design density.

Aircraft fuselages are basically cylindrical, with tapering ends, while cargo is basically square or odd-shaped. The inability to use much of the space in an aircraft is compounded by the necessity to pre-package loads, using containers or pallets. Now the load must be stuffed into a container, and the container into the plane, with wasted space at each step. Aircraft of different types do not always accept the same container, so for interlining, smaller containers which are mutually acceptable are used. This again reduces the utilization of space, the number of revenue tons and the load factor.

The design density is that ideal cargo density which will insure that the loaded aircraft will "cube out" and "weight out" simultaneously. The higher an aircraft's design density (lb./cu. ft.), the more dense is the cargo required to fill its weight capacity. Typical aircraft design densities and those of some cargo are shown in Table II-3.

The figures tabulated are factors which multiply the cost per ton mile of aircraft operation. These are the design densities divided by the cargo density. A "W" indicates the aircraft filled with pallets of this cargo will weight out before cubing out, and hence, with a full weight load, will have space left over. Notice that the average cargo



TABLE II-3

IMPACT OF DENSITY ON OPERATING COSTS PER AVAILABLE  
TON-MILE DOMESTIC SERVICE

(Table entries are factors for adjusting Design Weight Costs)

Avg. Pallet Densities by Shipper or Location		Design Density of Aircraft (Containerized Cargo)		
		DC-8-63 9.9 lb/ cu ft	747F 10.9 lb/ cu ft	707-320C 12.9 lb/ cu ft
Montgomery Ward	5.3	1.87	2.06	2.43
Average NY, Boston, LA	8.6	1.15	1.27	1.50
Freight Forwarders	9.5	1.04	1.15	1.36
Chicago-O'Hare	10.3	W	1.06	1.25
Time Magazine	20.0	W	W	W

SOURCE: L. M. Schneider in "The Future of the U.S. Domestic Air Freight Industry."

density for the markets surveyed is 8.6 lb/cu ft, which multiplies costs from 1.15 to 1.50 times for the three most popular freighter aircraft.

Besides load factor, the other major revenue determining statistic is aircraft utilization. This is the number of hours of block time, or revenue-producing flight time per day. For all aircraft, this number is decreased by routine and unscheduled maintenance, standby duty, and other factors. The remaining available hours are highly sensitive to the

types of routes flown. Short leg routes require multiple stops for ground operations, approach and departure. These phases of operation produce little or no revenue flight time and lower the plane's utilization. Long haul, non-stop, transcontinental or overseas flights, however, produce a high utilization rate increasing the productivity of the aircraft.

Table II-4 shows a comparison of two types of U.S. carriers, combination (passengers and freight), and all cargo.

TABLE II-4

## AIRCRAFT UTILIZATION AND LOAD FACTORS (1972)

Operation	Combination Carriers		All-Cargo Carriers	
	Acft Utilization hrs/day	Load Factor	Acft Utilization hrs/day	Load Factor
Domestic	7.05	44.0	9.36	57.0
International	8.04	47.2	11.48	68.1

SOURCE: Civil Aeronautics Board, Handbook of Airline Statistics, 1973

Aircraft utilization and load factor are higher for all-cargo carriers than for combination carriers, and higher on international operations than on domestic flights. This highlights some of the differences between combination, or a fixed ratio of passengers and cargo, and all-cargo operations. Freighters can be operated all the time, while combination

planes can only fly economically when passengers are available, which reduces their viability at night and through low passenger density airports. While all-cargo carriers depend totally on freight income, combination carriers do not. In fact, cargo revenues range up to 25% of total revenue for combination carriers. Therefore, passengers are their primary concern, and schedules are not built to conform to freight demands.

e. Cargo Costs. Figure 2-1 shows a typical breakdown of air cargo costs among various phases including the major categories of direct and indirect expenses. Mention must be made of an argument adopted from rail pricing strategists: the allocation (or non-allocation) of joint and common costs. Joint and common costs are incurred when a firm produces two products using the same resources. If the ratio of these products is constant, such as the ratio of cotton to cottonseed, then the costs which cannot be specifically attributed to either product are joint costs. If the ratio of the products varies, then these costs are common. The problem is that there is no effective way of allocating these joint or common costs to either product. Figure 2-1 compares the costs of air freight on freighter and combination aircraft. On a pure freighter, all cargo costs are fully allocated to the freight because there are no passengers. However, under the by-product costing scheme which assumes that the marginal cost of additional cargo is near zero, there is some distortion in the perceived direct and indirect costs.

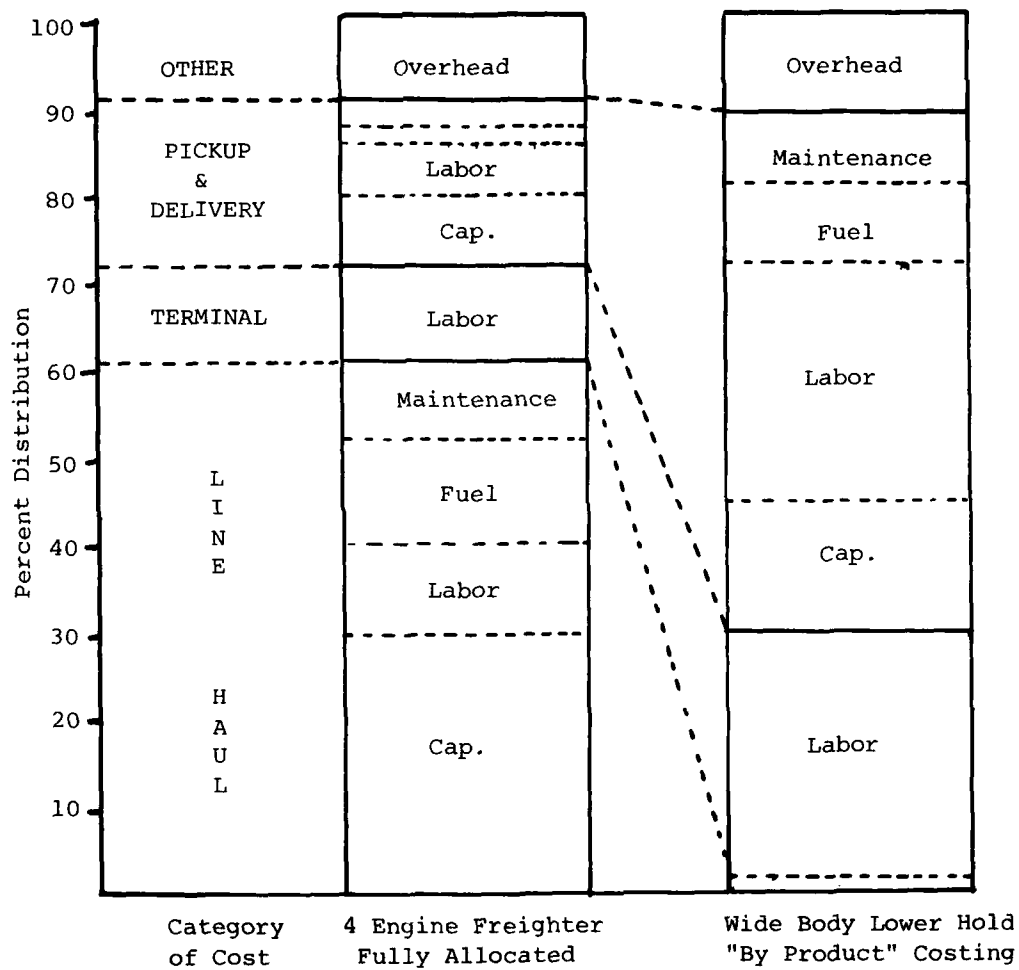


Figure 2-1. Distribution of System Cost by Cost Element.

SOURCE: U.S. Department of Transportation Staff Study on "U.S. Cargo Transportation Systems Cost and Service Characteristics."

The CAB has maintained, by regulation, that cargo rates charged by passenger airlines will not fall below those charged by all-cargo lines.<sup>12</sup> This procedure appears to be reminiscent of ICC pricing policies when deciding intermodal competition cases. The rates of one mode were not allowed to fall below costs of the next most efficient mode in order to "preserve competition."

Miller has indicated that this policy is probably efficient, since the opportunity cost of providing belly freight transport is the cost of using all-freight planes.<sup>13</sup> This viewpoint is the same as that favoring the SAT,<sup>14</sup> or Stand Alone Test, which asks: Are subscribers to a particular service of a multi-product firm paying more for their product than its stand alone cost, if it were produced by a single-product firm? This test has no basis in efficiency, either, but offers one possible answer based on equity considerations. Operators of "combi" planes have vigorously protested this CAB policy, mostly using the "revenue offset method," or by-product costing methodology. This says that belly space is inherent in all passenger aircraft, and since it cannot be used for passengers, and luggage doesn't begin to fill it up, that space is a by-product of flight, and has zero marginal cost. This, of course, would allow a great deal of pricing variability.

Miller (and the CAB) holds that a true by-product is a result of a joint production, that is, one which produces multiple outputs in fixed proportions, but that a by-product

has no value. Once the by-product becomes a saleable commodity, then it becomes a factor in determining the scale and orientation of the production. Cargo space in combination aircraft is therefore not strictly a by-product. In the short run, due to aircraft configuration, the mix of passenger and cargo space is fixed, and they are joint products. But in the long run, this mix is quite variable, and the two become common costs, since almost any combination is possible. Some aircraft can be reconfigured easily by the operator, so that the costs are common even in the short run.

f. Economics of Air Freight -- Conclusions. Our purpose here is eventually to build an intermodal network, so we should now ask, based upon this economic discussion, how are air freight costs related to those of other surface modes? The graphic answer is supplied by Figure 2-2. The air freight costs used here, and throughout the model, are those "allocated" on combination planes by using the cost per ton of pure freighters. Again, air freight is not competitive on a flat rate basis, but depends mostly on a high level of service to attract shippers.

We can see clearly now where the economies are in air freight carriage. Simplified, long hauls at maximum payload produce the most profit. Also denser-than-average cargo will lower cost-per-ton-mile. Containerization drastically cuts handling costs, but makes less effective use of aircraft interior space, while adding non-revenue weight. Quick change and convertible aircraft increase utilization, but

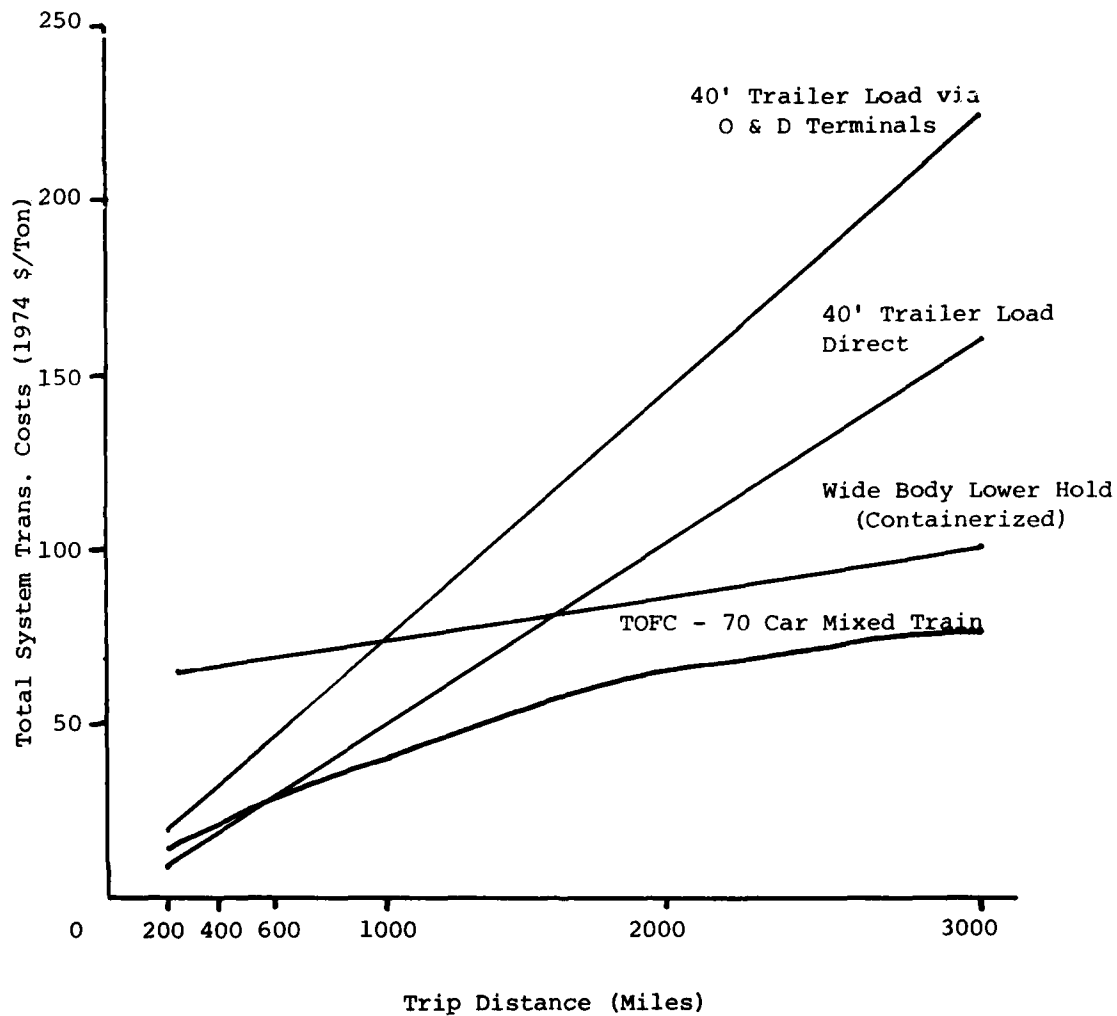


Figure 2-2. Comparative System Transport Costs.

SOURCE: U.S. Department of Transportation Staff Study on "U.S. Cargo Transportation Systems Cost and Service Characteristics," 1974.

penalize the carrier by adding extra weight and decreasing usable space. While it is known that larger planes will lower the cost per ton mile, it is also a fact that more cargo is required to break even on the wide-body aircraft. Also it is not known what the price elasticity of demand for level of service is, or whether flying fewer economical large planes will bring more revenue than flying smaller planes more frequently.

Finally, returning to the recent deregulation of cargo rates and routes, it would seem that this action would be disadvantageous for the all-cargo carrier, since it would give the combination carrier a reason to return to by-product cargo rates. However, the concurrent freeing-up of passenger rates has allowed these to tumble, insuring that both passengers and freight will be compensating the carrier, and freighter rates will be competitive. After many years of carrier warnings against passenger rate competition, the enormous demand for these new rates may lead to redefining what was formerly thought to be a price inelastic demand.<sup>15</sup>

Air freight and passenger deregulation, then, will necessitate a re-evaluation of the configuration of combination aircraft. Space allotted to passengers and cargo will be adjusted until, for a particular route, the carrier is economically indifferent to adding another seat or that much more cargo space. This ideal situation is subject to the cost of incremental changes in aircraft configuration. It is also true that while passengers usually demand round trip



(eventually) service from airport to airport, cargo is a one way contract, and usually door-to-door. This creates a cargo flow imbalance known as the empty backhaul problem. Since cargo does not originate at airports, some flexibility is permitted in satisfying the freight demand to adapt the cargo flow to airport capacity flow.

Investigating this flow in a network is the goal of this thesis. The model used here assumes that the surface and air modes act as a unified system to minimize costs. This, of course, does not occur because each mode is made up of many individual firms. However, if the result of air freight deregulation is a movement toward system optimization, this model can provide an ideal with which to compare present performance. If the goal is not system optimization, then a model such as this could be useful in indicating how much free-market cargo flows differ from the global optimum, and where these divergences occur.

## 2. Literature Review.

a. Air Cargo Terminal Simulation. The object in writing this computer simulation is to obtain a representative cost per ton for transshipping cargo through a terminal. Consequently, the literature cited does not encompass all there is to know about air cargo terminals, but includes works which aided in this objective. Descriptions of air cargo terminals were found to exist on several levels: verbal and diagrammatical, numerical, and in simulation models. Since the end product here is a simulation model, it is

logical to progress through the literature toward that goal.

The International Air Transport Association presents a comprehensive view of both passenger and freight terminals, including flow charts.<sup>16</sup> Because it is a reference manual, the level of detail is beyond the scope of this model, but it is conceptually instructive. Another such descriptive work was published by Hackney-Airlift Associates for the Boeing Company.<sup>17</sup>

Smith describes the general operation and economics of air freight terminals.<sup>18</sup> His work is replete with examples and photos of many of the world's largest terminals. This book also provides the values for many of the variables incorporated in the final model.

Moving on to the numerical level, Manalytics, Inc., produced a complete terminal analysis for the proposed Montreal Airport.<sup>19</sup> This work was used to obtain some parameter values as well, but its main contribution was as a test of the accuracy of the thesis simulation model. The results of this test are presented in Chapter III, Section 4.

Two simulation models of air cargo terminals were found which aided somewhat in understanding the problem to be modeled. The aim of Stites' simulation was to advocate such models as systems analysis tools.<sup>20</sup> He used the model primarily to test the sensitivity of variously configured terminals to such inputs as per cent palletized cargo and throughput capacity. The Army's Construction Engineering Research Laboratory (CERL) presented a quite detailed simulation.<sup>21</sup>

The object was the analysis of a proposed cargo terminal which was being considered by the Air Force. The program was designed to determine potential bottlenecks and to evaluate the best construction oriented strategy that could be taken to eliminate them. Using deterministic and stochastic events, the program did pinpoint modifications to reduce throughput time.

b. Air Freight Network Model. This "network" actually consists of the two math programs combined with a quadratic term from the simulation model used in the objective function. These models and their interaction are discussed in detail in the next chapter. The first part of the linear program consists of a "transportation problem" which routes cargo to regional airports by surface mode. The second part is a fleet assignment model which assigns aircraft to routes to carry the cargo from the airports to the destination region.

Hitchcock's classic transportation problem came about as an adaptation of linear programming techniques to optimize the movement of a commodity from several sources to several sinks, given a cost for each link.<sup>22</sup> The techniques he used have been improved upon greatly, but this is a simple method for formulating this part of our network.

A great deal of work has been done in the area of optimal routing of aircraft to deliver passengers and cargo. Many of these models are in fact the improvements made to Hitchcock's model. Dantzig extended the model to a basic fleet assignment model, which was the forerunner of such models in

use by airlines today.<sup>23</sup> Dantzig's model used a set of non-stop routes among network city pairs. Each route had a fixed demand, and there were a limited number of aircraft to serve the demand.

Simpson lists a direct successor to Dantzig's program as Fleet Assignment 2 (FA2).<sup>24</sup> The major change is that multi-stop routes are permitted. Aircraft load factors, used as a capacity averaged over the fleet, are also considered. Also a minimum level of service to passengers can be assured by specifying a minimum number of flights with a maximum number of stops on each. This linear program, FA2, is the basis for the quadratic program used in this thesis.

A heuristic model which uses another program to generate the routing possibilities and permits manual decision-making at specific points was written by Fetter, et al., for the Rand Corporation.<sup>25</sup> The linear program differs from FA2 in that in minimizing the cost of operating the system it also includes in the objective function a term representing cargo left behind which must be shipped by an alternate mode, and a term for the unused capacity. The route generator program selectively eliminates many routes which are bigger than the "best" route by a certain percentage. This lightens the computational load on the linear program and hence lowers the cost of running the package.

What appears to be the most comprehensive package for fleet planning, routing and scheduling was written by Jessiman and Ward for the Department of Transportation.<sup>26</sup> This ten

volume work utilizes a program which minimizes the social (travel time) and economic costs. This complex program is detailed enough to represent actual networks and to solve airline and regulatory problems.

Finally, in an effort to find the optimal connectivity in a hypothetical network, Gordon and de Neufville presented an analytic solution.<sup>27</sup> This procedure, given a fixed budget, minimizes the total delay to all passengers, which includes weighted values of waiting time and travel time. Minimizing this social cost led them to the conclusion that less connected, hub-type networks are superior to highly connected networks and that larger, less frequent planes and parallel routes between city pair airports increase delay.

## CHAPTER III

### MODEL DEVELOPMENT

#### 1. Overview.

This model consists of three distinct programs which serve to establish the overall objective function and constraints, generate aircraft routes to serve the network, and estimate a convex average cost function to represent transshipment at the nodes. These processes are described in the following sections: quadratic program representing the network, route generator, and simulation model. The final section in this chapter describes the experiments to be undertaken on the network.

Figure 3-1 describes the interaction of the three programs which act to produce an optimal solution.

The object of this experiment is to minimize the cost of moving all the air freight supplied within a region to a destination outside the region. Our hypothetical region is made up of four nodes which serve as sources, representing cities. There are four nodes associated with these cities which represent airport terminals. The cargo is transported from each city to any of the four airports by a surface mode. The freight is then processed through the terminal, and delivered by aircraft to either another node within the region for transshipping through that terminal to another aircraft,

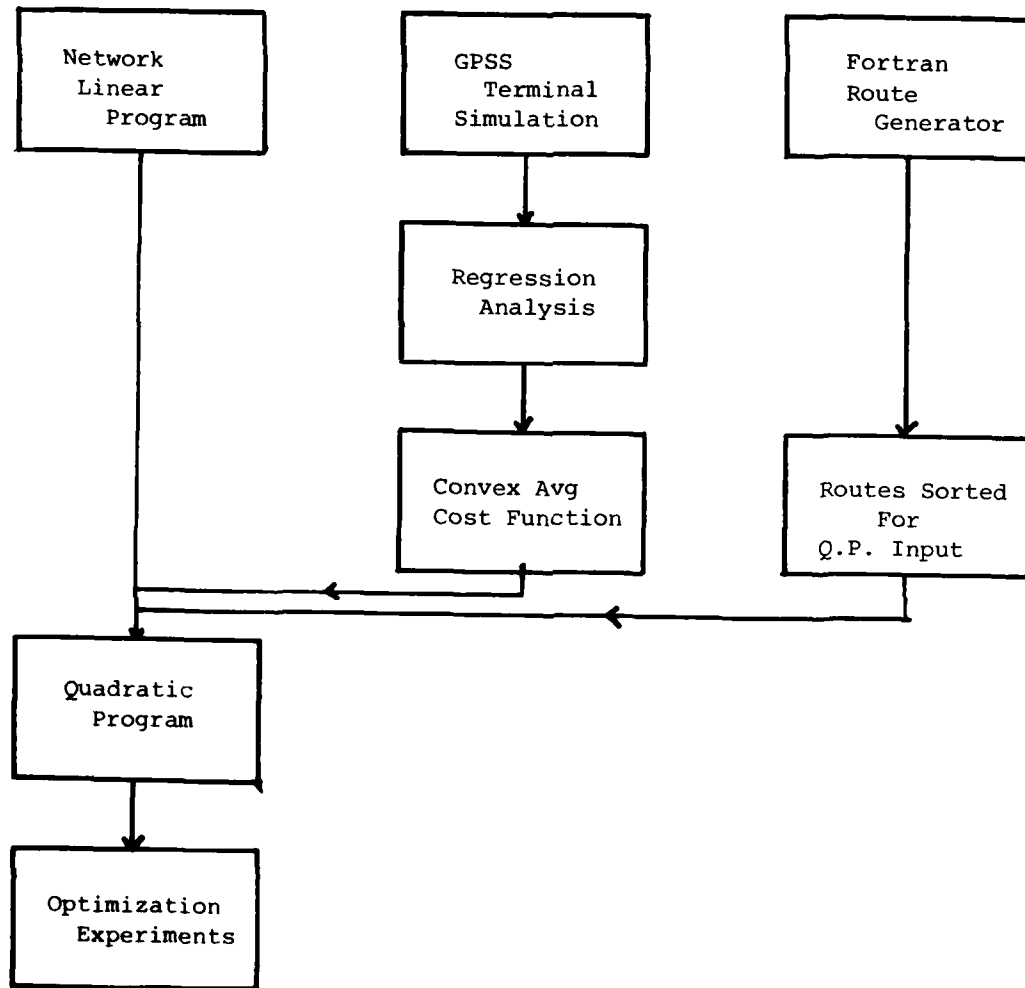


Figure 3-1 Model Flow Chart.

or directly to the destination. The ultimate destination of all cargo is represented by a fifth node, which is only a sink for cargo. Figures 3-2 and 3-3 show first a plan view of the network, and then a "side view" with the airport nodes raised above the city nodes for easier comprehension.

Although this may appear to be a nine node network, the method of solution is more like solving two networks simultaneously, one from city to airport, and the second from airport to airport. The output of the surface solution is the input for the air problem. The quantity moved is always tons of cargo, although on the surface it moves as a single flow, while in the air it moves in increments of aircraft capacities.

The aircraft routing possibilities are enormous, even for such a small network. Therefore, a FORTRAN route generation program was written to examine all the possible routes, then eliminate most of them on the basis of excessive range for aircraft, or excessive utilization of aircraft. This condensed list of routes is then used in the math program, which identifies the optimum routes to move the freight.

The cost of transshipping cargo through a terminal, either initially from truck to air, or subsequently if an air to air transshipment is desired, is supplied by the simulation model. This consists of a detailed air freight terminal simulation model which was run at different levels of throughput to determine a quadratic cost function. This cost function is then used as a term in the objective function of



5

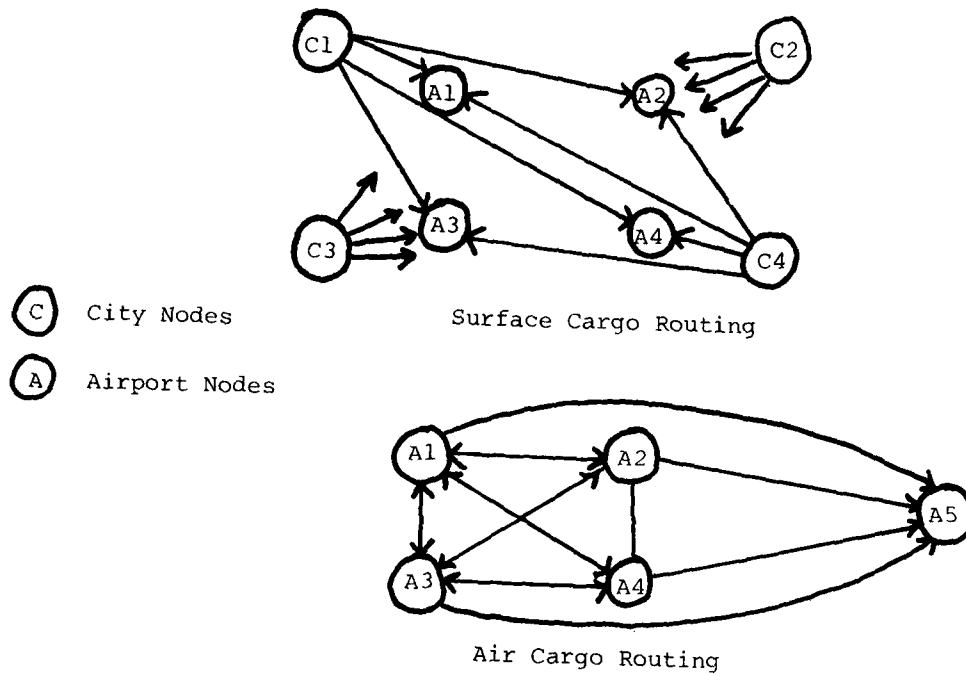


Figure 3-2 Network Plan View.

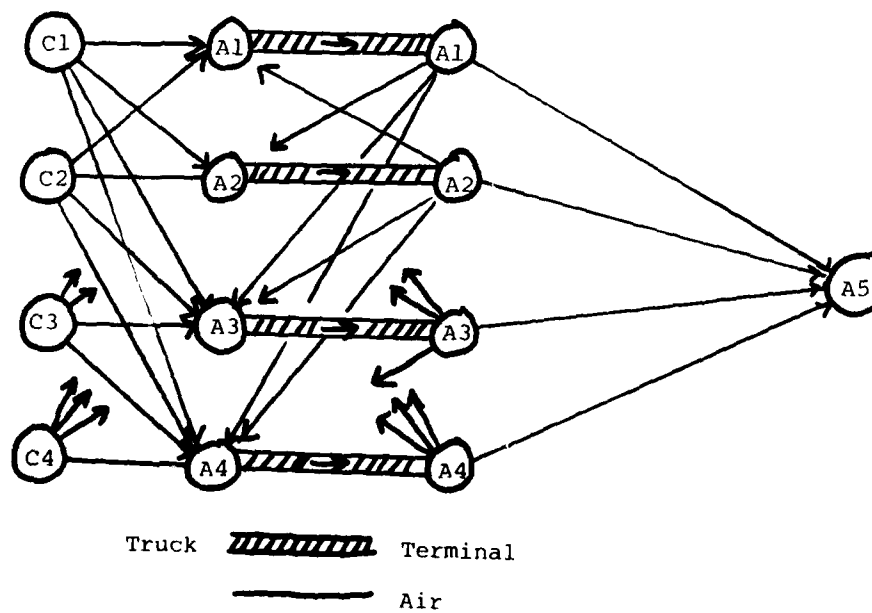


Figure 3-3 Network Expanded View.

the math program.

A number of major assumptions are made in this model:

1. Demand for air freight transportation is constant and is not affected by the price or level of service provided. This price inelasticity is a common assumption in such models, although Gordon and de Neufville suggest that use of a demand function tied to network performance, in conjunction with several iterations, would allow for a responsive demand. This procedure would consist of running the model, finding the optimal system cost, computing the price for transportation, then using the demand function to adjust the cargo demand. The model would then be re-run, and this iteration repeated until the demand change between runs was less than some desired amount. This would be the assumed equilibrium cargo flow.
2. All cargo presented for shipment is considered as "tons," making no allowance for the added cost of handling and shipping loose, odd-size or low density cargo. This assumption was made to simplify computations.
3. Trucking costs consist of a terminal charge of \$40. per ton and a line haul cost of \$.60 per ton mile. These figures are based on a two ton shipment size, and inflated to present dollar values from figures used by A. F. Friedlaender.<sup>1</sup>

4. Aircraft costs are cited as direct costs and are applied to a route flown by a particular type of aircraft. Again a fixed cost per segment plus a cost per hour are used. The figures for costs and capacities are approximations only. Capacities allow for a 67% load factor. In reality the range, load, cargo density, and other factors will cause the cost per hour to vary between routes. The assumed parameters are set forth in Table III-1, as follows:

TABLE III-1

## ASSUMED PARAMETER VALUES FOR AIRCRAFT LOAD AND COST

Size	Capacity (tons)	Fixed Cost per Segment (\$)	Direct Cost (\$/hr)	Similar to
Small	10	325	1300	DC9-33
Medium	25	425	1700	B-707
Large	50	500	2000	B-747F

SOURCE: Derived from tables in "Air Freight Operations, Economics and Marketing."

5. Air freight terminals exist at each airport, and must remain open, whether they are used or not. This implies an unavoidable fixed cost on the network.

6. All cargo tendered is specifically air freight, and will move on the system being modeled.
7. The cargo backhaul from the destination node is not considered, because this model is limited to observing the flow of outbound cargo. Hence, aircraft flying to node 5 are not returned, although there certainly is a necessity for this in a real situation. It is assumed that return cargo does exist in a manner symmetrical to outbound cargo.
8. This is not an aircraft scheduling model and the aircraft assignments it uses to minimize costs may in fact be difficult to schedule effectively. However, considering the theoretical nature of the network and the purpose of the experiments, this does not appear to restrict the use of the model.
9. Although the model never directly considers shipment time enroute, it is constructed to insure that cargo is moving in trucks, aircraft or resident in a terminal awaiting air pickup. Truck shipments which exceed 300 miles are excluded from the model. The Manalytics study indicates that air freight shipments are usually too time sensitive to travel this distance by surface mode.

## 2. Quadratic Programming Model.

The model consists of three cargo movements: from city to airport, through the airport terminal, and by air to

either another terminal or the final destination. Our objective is to minimize the total cost of moving cargo across this network. The network model consists of segments, or directional arcs, which connect each two points. An aircraft route consists of one or more segments, flown in order by one aircraft. The subscript  $r$  will always indicate an assigned route number, while  $a$  will show what type (small, medium, large) aircraft is involved. When describing arc or segment movement, the subscripts  $pq$  will be used, while  $ij$  will show a movement of cargo from origin  $i$  to destination  $j$  on the same route. This does not exclude  $ij$  from being consecutive stops on this route. First, we must define the terms to be used, as in Table III-2:

TABLE III-2

## DEFINITION OF QP TERMS

---

$A_a$	=	number of type $a$ aircraft available
$AC_{ra}$	=	cost of flying aircraft $a$ on route $r$
$BT_{ra}$	=	block time for aircraft $a$ on route $r$
$CAP_a$	=	capacity of aircraft type $a$
$F_{ra}$	=	number of flights of aircraft $a$ on route $r$
$N_{\min pq}$	=	minimum direct service flights required on segment $pq$
$PC_i(\Sigma TA_{ij})$	=	total cost function for terminal $i$ (quadratic term which is actually of the form:

---

$$d(TA_{ij})^2 + b(TA_{ij})).$$

$S_i$	=	supply of cargo tons at city i
$TA_{ij}$	=	tons airlifted from terminal i to terminal j, or where j=5, to final destination
$TA_{ijr}$	=	tons airlifted from i to j on route r
$TC_{ij}$	=	cost per ton by truck from city i to airport j
$TT_{ij}$	=	tons trucked from city i to airport j
$U_a$	=	maximum hours of daily utilization of aircraft a
$R_{pq}$	=	set of all routes which cross segment pq in that order
$R'_{ij}$	=	set of all routes which serve air O-D pair ij

a. Statement of Model. Using this terminology the model can be stated:

Objective Function:

Minimize operating costs

$$\text{MIN} \sum_{i=1}^5 \sum_{j=1}^5 TC_{ij} TT_{ij} + \sum_r \sum_a AC_{ra} F_{ra} + \sum_{i=1}^4 PC_i \left( \sum_{j=1}^5 TA_{ij} \right)$$

The three terms represent trucking costs, aircraft costs and terminal costs (quadratic term).

Constraints:

1. All cargo supplied at cities will be trucked to an airport.

$$\sum_{j=1}^4 TT_{ij} = S_i \quad \forall \text{ sources } i$$

2. All cargo trucked or airlifted to a regional airport will leave on a flight.

$$\sum_{i=1}^4 TT_{ij} + \sum_{i=1}^4 TA_{ij} = \sum_{i=1}^5 TA_{ji} \quad \forall_j 1 \text{ to } 4, i \neq j$$

3. All cargo supplied at cities will ultimately be airlifted to node 5, the destination.

$$\sum_{i=1}^4 TA_{i5} = \sum_{i=1}^4 S_i$$

4. For all possible origin and destination airports, the routes serving them carry all the cargo that moves between them. This, in effect, defines the route specific cargo movement which is used in the next constraint.

$$\sum_{r \in R_{ij}} TA_{ijr} = TA_{ij} \quad \forall \text{ air O-D pairs } ij$$

5. Over each arc  $pq$ , the cargo flown on each route crossing  $pq$  must not exceed the capacity of the aircraft used on that route. This includes, for routes traversing  $pq$ , the sum of all cargo picked up at  $p$  or earlier, destined for  $q$  or stops further along the route.

$$\sum_{r \in R_{pq}} \sum_{\substack{i < q \\ p < j}} TA_{ijr} \leq \sum_{r \in R_{pq}} \sum_a CAP_a F_{ra} \quad \forall \text{ arcs } pq$$

6. For each aircraft type, the average number of aircraft hours flown must not exceed a specified total utilization.

$$\sum_r BT_{ra} \cdot F_{ra} \leq U_a A_a \quad \forall \text{ aircraft types } a$$

7. A minimum level of direct service must be supplied between each airport and selected destinations.

$$\sum_{r \in R_{pq}} \sum_a F_{ra} = N_{\min pq} \quad \forall p \text{ (1 to 4)}$$

A number of additional constraints can be added to adapt the model to specific situations. These might include:

1. A maximum number of aircraft permitted to land at an airport. This could represent a congestion or capacity restraint.
2. Aircraft routing constraints, which would assure that all aircraft movements balanced at every station. This is not necessary for the purpose of this model, since we are not assuming a backhaul problem, thus we are not optimizing the return flow of aircraft.

The dividing line between the trucking constraints and the air movement constraints lies between constraints 2 and 3.



These are a straightforward statement of a transportation problem, ensuring that all cargo moves by truck to and through a terminal. While the necessity of constraint 3, insuring that all cargo reaches node 5, is obvious, the justification for constraint 4 is not as apparent. There is a definite necessity to use route specific air cargo movements,  $TA_{ijr}$ , in order to observe the optimal flow of aircraft during experimentation. Because this route specific flow appears elsewhere only in constraint 5, its role in 4 is to define exactly which O-D cargo flows these routes are supplying. Note that this is the only constraint where these route flows are summed. A user of this program may wish to replace this with a tighter constraint which may fit a particular situation, such as maximum use of a congested route, etc.

Constraint 5 has the purpose of insuring that for each segment (arc), each route across it is carrying no cargo flow which cannot be carried by the aircraft flying that route. Examining each route rather than summing routes has the effect of increasing the number of constraints somewhat, but also is more descriptive of an air cargo network.

Constraint 6 provides a method of describing a fixed fleet of aircraft. By changing the numbers of each type of plane available, the user can simulate a specific fleet or test the sensitivity of the model results to fleet changes. Note that the Fortran Route Generator program described in the following section eliminates many of the routes which will overutilize the aircraft, and all the routes beyond the

plane's maximum range. This is done before the routes are considered by the quadratic program; this reduces processing time and costs considerably.

The final constraint represents a test related to the discussion of cargo on combination planes in Chapter II. Since we are assuming that demand for cargo transportation is constant, the significance of a minimum level of direct service between city pairs is to attract passenger demand. This program will test the opportunity cost of this type of service to optimal cargo movement.

b. Model Translation. The translation of these parameters into terms and relationships usable by the quadratic programming package is the job of the Fortran route generation program discussed in the next section. The package used is a part of the Multi Purpose Optimization System (MPOS).<sup>2</sup> This system allows algebraic, matrix and packed input of variables. To process the quadratic objective function term with linear constraints the "Beale's Algorithm" option is selected. This allows optimization along a convex objective function while the standard MPOS options require linearity throughout the program.

c. Output Interpretation. The standard MPOS output is requested which includes a summary table showing the activity levels for all primal variables, slack values for constraints, and opportunity costs (shadow prices) for dual variables corresponding to each constraint. Finally the output lists the value of the objective function.

Alternate optimal solutions, where several combinations of the variables are optimal, are to be expected when such a large number of routes is used. While this may make the solution look "loose" it is actually a boon to a user who may have other decision bases which he could not insert in the model. For instance, the planner who finds that he can route aircraft through either of two airports without affecting the optimal system cost might choose the airport which is least sensitive to off-hour aircraft noise. Since this decision basis is not easily quantifiable it could not easily be included in the model. It is the presence of multiple optima which allows such a choice of solutions at the same cost.

The value of the dual variable, opportunity cost, or shadow price is listed for each constraint. This value indicates how much the objective function will decrease as the value of the right hand side of this constraint is increased by one unit. In other words, the value of the dual variable indicates the value of one additional unit of a particular resource. This will indicate probable places to add aircraft, or reduce tonnage. Constraints with slack (not binding) will have a zero opportunity cost because modifying their right hand sides will not affect the objective function.

### 3. Route Generator.

Due to the great number of possible routes, and the degree of sorting required prior to use in the math program, a FORTRAN route generator program was written. As the program

is full of loops and transfers, it will not be discussed in detail here. A flow chart, listing and sample output are provided in Appendix II.

Basically the program uses an input of network and aircraft parameters, builds basic one leg routes, then adds to them gradually, examining each new route's suitability to the network and the planes. When the program finds that it can no longer build on the routes it has without violating aircraft utilization or range constraints, it stops generating routes. By allowing only routes which are within allowable range and utilization, this program restricts the set of routes which the quadratic program must consider. This, in turn, significantly reduces the number of variables in the quadratic program, with considerable savings in computing costs.

The second major function which takes place is the sorting and listing. The sequential route numbers and stops made are listed because in the MPOS "packed" format only variable numbers are used, and the listing provides a dictionary for interpreting route information. The sorting is required by quadratic program constraints numbers 4 and 5, which require that select routes, which serve specific O-D's or segments, be summed or examined. Most of the complication in the FORTRAN program arises as the routes and their stops are shuffled among various arrays during the sorting.

The program output can list these sorted variables on a disk file for direct insertion into the math program or on

paper for manual input. The listing in Appendix II and the sample output are for printed output.

#### 4. Simulation of an Air Freight Terminal.

a. System Definition. The purpose of this model is to produce a single quadratic cost function which will be used in the objective function. It is not an integral part of the model, in that it is not re-run for each experiment. The cost function is a single measure of the expense of transshipping cargo through an air freight terminal. The system under consideration is limited to the major participants: trucks and planes arrive to deliver the cargo; the terminal unloads, sorts, stores, retrieves, assembles, and prepares the cargo for loading; other planes arrive, are loaded, and depart from the system. The program was created to be robust, with most of the parameters stated as variables, in order to enhance its use for other purposes.

b. Model Formulation. The terminal operations which are simulated are shown graphically in Appendix III-1. There are two types of trucks used, long haul and local. Cargo arrives in the form of loose, palletized, or odd-size loads. The sorting and storage takes place immediately upon arrival by truck or plane. Prior to a departure, the load is retrieved from storage, and built into pallets. The pallets and odd cargo are stored on a ready line until loading takes place and the plane departs.

The model allows the user to select many options, such as plane size, per cent palletized and loose cargo, and other

parameters. One variable to which the model proves to be quite sensitive is the "location index" which accounts for the higher land values and wage rates in some locations. The model uses the location index in calculating wages (operating costs) for all activities in addition to the value of the land used for truck and airplane parking and for terminal facilities. The result of running the model for one peak period is a dollar cost for each major expense area, a total cost, and a cost per ton transshipped.

c. Data Preparation. Data for constructing the constants used was combined from many sources. The greatest amount came from:

- i. an air cargo terminal study by Manalytics, Inc.<sup>3</sup>
- ii. P. S. Smith's text, Air Freight Economics, Operations and Marketing<sup>4</sup>
- iii. visits to the headquarters of United Airlines and the Military Airlift Command, USAF.<sup>5</sup>

d. Model Translation. The simulation was written from the system flowcharts shown in Appendix III-2, and the GPSS V listing with annotations is shown in Appendix III-7. The following GPSS entities were used:

Transactions: trucks, planes and loads

Transaction Parameters:

- vehicle capacities
- kilograms loose cargo
- kilograms palletized cargo
- parking space used

Storages:

- four types of cargo storage areas
- two types of parking areas
- two types of sorters
- two types of cargo handling equipment

e. Validation. During and immediately following the construction of this simulation, many validation runs were made to increase confidence in the model. With so many parameters, varying each of them would have been quite tedious. However, varying the major capacities, costs and rates gave encouraging results. Massive failures due to overloading are avoided, because the model is composed of expanding facilities, which enlarge (at a cost) to relieve an increased usage rate. This feature is a direct result of the service orientation and time sensitivity of air freight operations.

The final validation step consisted of running the model for a wide range of tonnage values and plotting these against cost per ton on a graph. By superimposing a cost curve from the Manalytics project, the validity of the simulation model was strengthened. The curves were quite closely aligned in the middle range, but varied at low throughput.

f. Experimentation. The experimentation was performed to produce points from which a regression could be run to find the most likely quadratic equation to represent the model. A parabolic function was selected because such an equation was simple enough to fit into a math program objective function. It also lends curvature to the total cost

function for terminals, which appears to represent these costs more accurately than does a simple linear function.

A total of thirty readings was taken, and in such a manner as to minimize the variance at the center point, as suggested by L. Ott and W. Mendenhall.<sup>6</sup> The resulting quadratic equation was:

$$\hat{y} = \underset{(34.2)}{.00001309}x^2 - \underset{-(52.1)}{.03342}x + \underset{(230)}{38.873} \quad (t\text{-values})$$

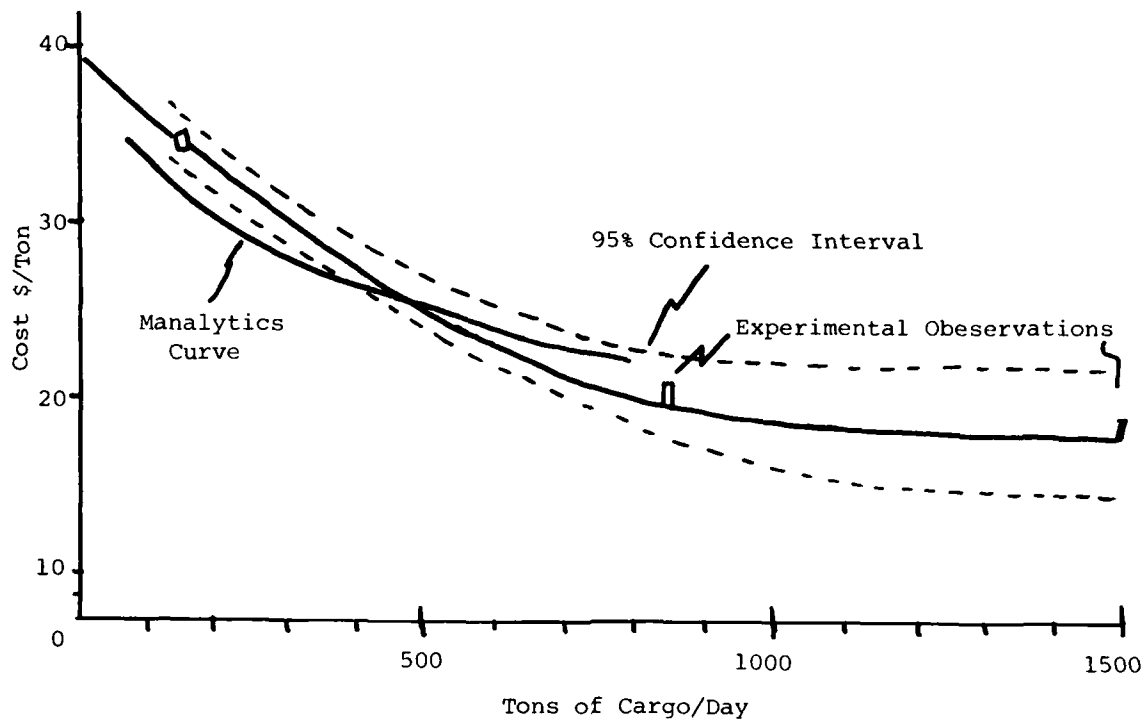
The  $R^2$  value was .998, and all values are significant at the 95% level. The curve and associated confidence intervals are shown, along with the Manalytics curve, in Figure 3-4.

##### 5. Experimentation.

The object of this thesis is ultimately to conduct experiments on the sample network to determine the characteristics of optimal cargo flow. We will be examining the degrees of connectivity and centralization exhibited by the network under various configurations. The connectivity is a characteristic which describes the amount of direct traffic links versus indirect traffic flows. A network in which every pair of points is directly (non-stop) linked is a completely connected network. One in which all traffic between outlying nodes is routed indirectly through a central hub is less connected.

The centralization we will be looking for is a tendency for gathering many operations into a regional center node or hub. Certainly this phenomenon is observed in many air freight regions today, where huge hub airports have developed near





	Measurements		n=30
\$/Ton	150	825	1500
34.25		20.12	17.81
34.03		20.79	18.26
34.10		19.48	18.35
34.10		20.73	18.53
34.23		20.73	17.99
34.17		19.43	17.56
34.13			18.03
34.19			18.56
34.04			18.60
34.17			17.91
34.24			17.76
34.21			18.93

Fitted quadratic equation:

$$Y = .00001309x^2 - .03342x + 38.873$$

95% Conf. Interv.      .0000123      -.0347      38.527  
                                  to            to            to  
                                  .0000139      -.0321      39.22

Plotted - - - -

$$\mu = 24.9803$$

$$\sigma = 7.6648$$

Figure 3-4. Simulation Cost Curve.

cities such as Chicago, New York, and Frankfurt, F.R.G. This centralization typically means that cargo is trucked to this airport from great distances, bypassing other large airports on the way. It also may include the scheduling of a great number of direct flights from this hub to the destination region. A centralized network may also include interlining between different size aircraft. Here smaller aircraft flying direct or indirect routes may airlift cargo to this central hub, where it is transshipped through the terminal and loaded on large planes for the direct trip to the destination.

To conduct the experiments we will start with a basic network which is small enough to permit universal trucking within the region. The tons of cargo at each city will be approximately even, and the destination region will be close enough to be within the range of large and medium size planes. Table III-3 lists the applicable truck and aircraft characteristics, while Figure 3-5 displays the hypothetical base network.

The five experiments which will be conducted are designed to highlight some of the major differences between real-world regions. The network will be modified for each of the five runs, and its performance contrasted with that of the basic network. Finally, conclusions will be drawn regarding the connectivity and centralization exhibited under various conditions. The five experiments (shown graphically in Figure 3-6) are:

TABLE III-3

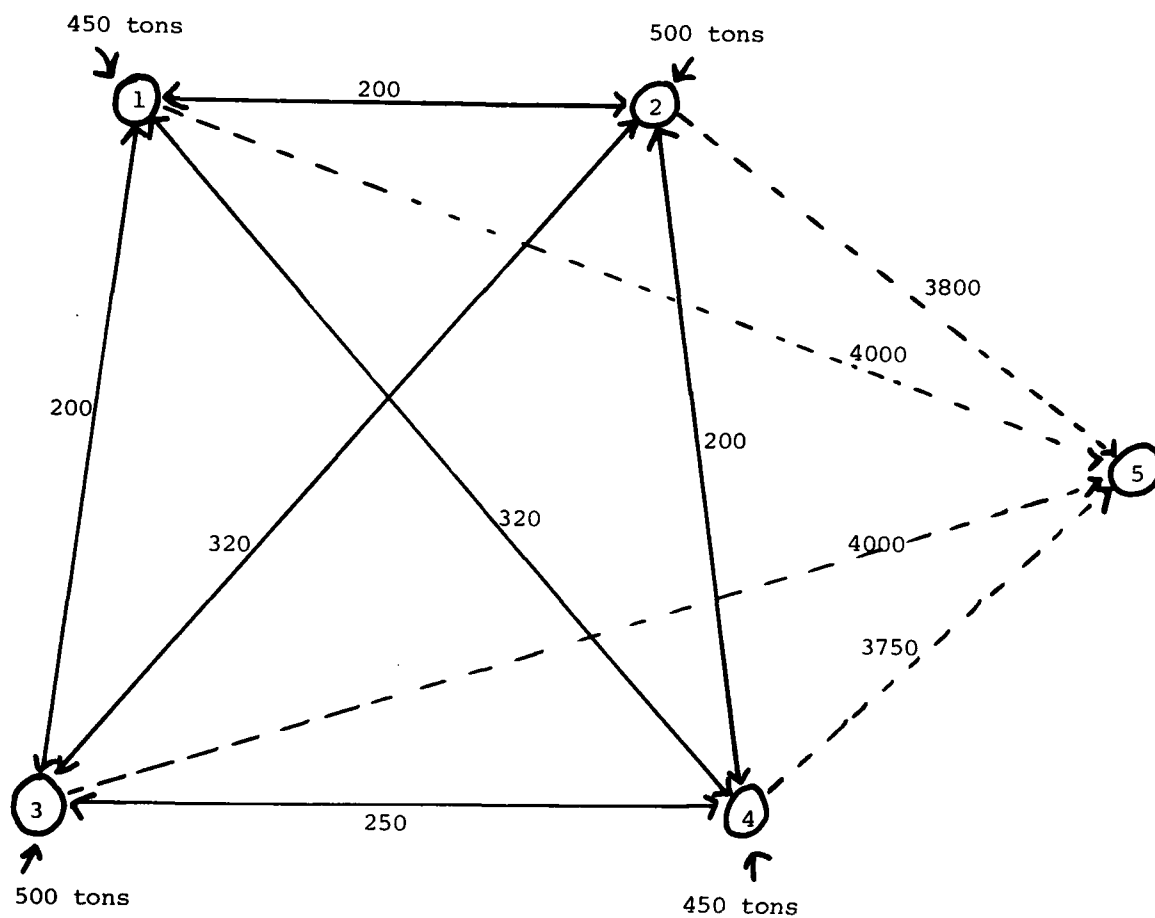
## SUMMARY OF NETWORK AIRCRAFT AND TRUCK CHARACTERISTICS

Vessel	Capacity (tons)	Range (mi)	Fixed Cost (\$/leg)	Speed (mi/hr)	Variable Cost (\$/hr)
Small Plane	10	2000	325	450	1300
Med Plane	25	5000	425	500	1700
Lg Plane	50	7000	500	500	2000
Truck	N/A	300	40 \$/ton	N/A	.60 \$/ton mi

1. Enlarged Network. The size of the region will be increased to a degree which excludes intercity truck traffic. This will simulate a large region in which there is no effective competitive surface mode, such as Alaska, South America, or Africa.

2. Geographically Isolated Node. Here a surface barrier will be erected in the basic network which eliminates truck traffic from that node to any other. The object is to represent a city which is either on an island or cut off from the region by a geographic or climactic obstacle. In the model, this will be accomplished by constraining the tons trucked to and from this city to zero.

3. Long Distance to Destination Node. Using the basic network again, the distance to node 5 will be increased until

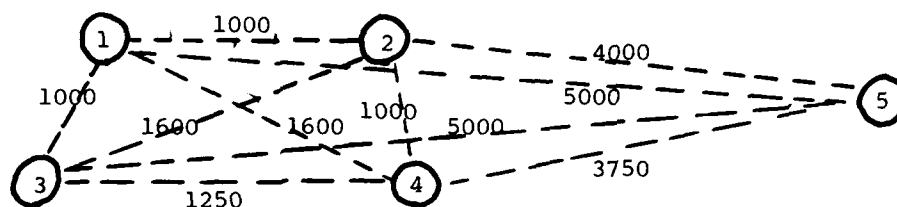
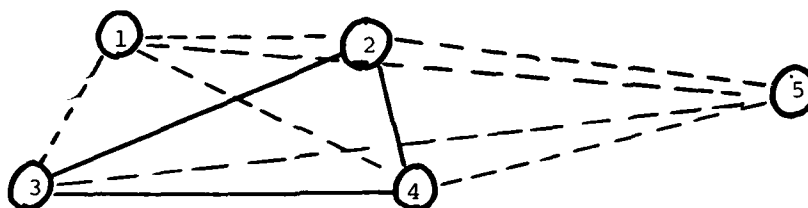
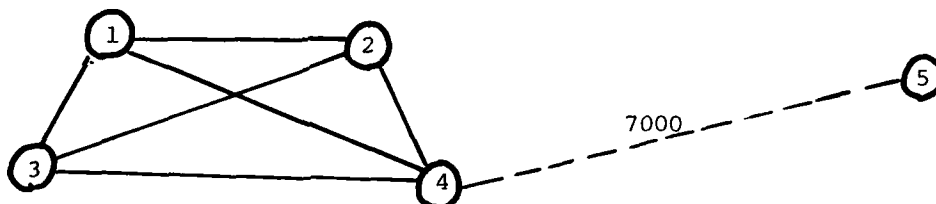
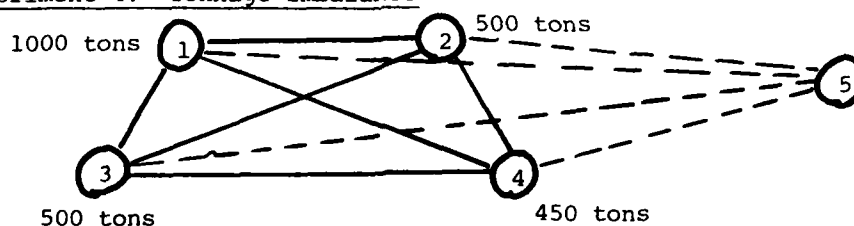


Standard Distance From a City to its  
Airport = 15 miles

————— Air and Truck Miles

- - - - - Air Miles

Figure 3-5. Hypothetical Base Network.

Experiment 1: Enlarged NetworkExperiment 2: Geographically Isolated NodeExperiment 3: Long Distance to Destination NodeExperiment 4: Tonnage imbalanceExperiment 5: Aircraft Inventory Shift

(see base network)

————— Air & Truck  
 - - - - - Air Only

All distances are those of the standard network unless noted.

Figure 3-6. Experimental Networks.

only the long range, large planes can reach it, and then only from one city. This will enable us to examine the indirect routes which occur, as well as any transshipment activities which take place at the airport which is within range. This condition exists in many areas of the world, where intercontinental traffic can launch from only a few selected points. Many of these airports have grown to be non-central hubs because of this fact.

4. Tonnage Imbalance. The tonnage of air freight tendered at one city will be increased substantially, without changing the minimum level of service constraints. This will enable us to observe the network's reaction to a shift of manufacturing from one city to another within a region. It also simulates the growth of one city into an important "air freight market," producing goods amenable to air carriage, while other cities remain at current levels of such production.

5. Aircraft Inventory Shift. This run will examine the possibility of increasing the allotment of one type of aircraft, while reducing that of another type. This experiment will be based on the performance of the four previous models, and the opportunity costs indicated by them for each aircraft utilization constraint. The experiment will only be performed on the basic network. The assumption which will make this substitution somewhat unrealistic is that, although aircraft capitalization costs are included in the Direct Operating Costs per flight in the objective function, the "trade" from one type to another is free. This, of course, is not usually

the case in actuality. However, for our purposes, observation of the network, this assumption does not appear to cause great distortion.

Finally, a series of experiments will be performed on the base network to determine the sensitivity of optimal flow to changes in aircraft, trucking, and terminal costs. These tests are essential not only for understanding why the optimal solution is as stated, but for indicating the probable effects on this solution of cost changes. The results of these five experiments and the sensitivity analysis will be described in Chapter IV.

## CHAPTER IV

### RESULTS AND CONCLUSIONS

The experimental process outlined above was to have been carried out with three runs of the Fortran Route Generator. These would transform the parameters of the three basic networks into truck and aircraft costs, aircraft routes, and origin-destination pairs and segments served by each route. The three networks involved were the basic case, the enlarged region (Experiment 1), and the distant-destination network (Experiment 3). Additionally, each case was to be run with and without a requirement for intra-regional flight service and Experiment 3 was to be run with the minimal number of large aircraft. Also, Experiments 2, 5 and 6 were to assess the effects of the isolation of a node, a tonnage flow imbalance, and an aircraft inventory shift, respectively. Finally, three runs of the basic case were to examine the sensitivity of the optimal flows to changes in the terminal and truck costs. This called for 13 runs of the network math program.

However, developments during the course of these runs led to modifications in this plan. The first problem was that of resource limitations of computer size. The original Route Generator produced the set of routes for the basic network shown in Appendix II. When this list of 76 possible



routes was translated into math program terms, it produced a problem with 528 variables and 46 constraints. This was more than twice the capability of any of the quadratic programming algorithms in use at Northwestern. It was therefore decided to eliminate four-stop routes from consideration, and use only two and three stop routes.

The next change concerned the use of the quadratic cost function itself. The average total cost function for terminal operations shown earlier possessed the convexity required for use in this program. However, the dependent variable in the equation was "\$/ton," and its use in the objective function required that the equation be multiplied by a variable representing tons to produce a dollar cost. This of course would have left a cubic equation, which was not acceptable to the program. The solution was to rerun the regression on points representing total cost to produce a quadratic function directly usable in the objective function.

This regression was completed, and the resulting equation was:

$$y = \underset{-(2.27)}{-.0010339x^2} + \underset{(23.7)}{18.123x} + \underset{(12.1)}{2428}$$

All variables were significant at the 95% level, but  $x^2$  was not significant at the 98% level. This indicated that the total cost function approached linearity in the range of the statistical tests. It can be seen that the function was no longer convex, but instead described a concave parabola which would eventually produce a negative cost for extremely large tonnage values. This presented no immediate problem, because

additional constraints could be written which would hold terminal activity to the upward sloping area of the curve. Unfortunately, all of the quadratic programming algorithms will check that the objective function is convex before commencing the solution, and the more efficient programs will not solve concave problems. Beale's algorithm did offer a solution for a small experiment, but it would not solve the same experiment when the requirement for a minimum number of flights was included. Also, it would not solve the larger problems due to computer resource limits.

It was decided at this time to use a completely linear objective function. The following points led to this decision:

1. With the concave terminal cost function, only a portion of the experiments could be solved using a quadratic program; the rest had to be solved by a linear program.
2. The concave function also raised the possibility that the algorithm would produce an incorrect or non-global solution.
3. The quadratic term in the cost function was not significant at the 98% level.
4. A regression on the total cost points produced a linear equation with an  $R^2$  (adjusted) of .998 with terms which were significant at the 99% level. This equation was:

$$y = 16.41679x + 2755$$

(111)                      (18.3)

5. Finally, two runs on the same math program, one with linear terms and one with quadratic, produced minimum objective

function values which were within 0.1% of each other. This difference was clearly more acceptable than the problems which would have come with continued use of quadratic terms.<sup>1</sup>

The final change of plans involved the deletion of Experiment 2, the isolated node case. This step was taken because early results showed that this case would have been redundant. This will become clear when the results are analyzed. The number of math program runs was therefore reduced to twelve.

These twelve runs resulted in seven different types of network solutions. The numerical results are listed in Table IV-1, while the seven types of optimal network flows are shown graphically in Figure 4-1. In an effort to compare the connectivity and centralization of each network solution, absolute numbers have been assigned to them based on the optimal flows. To describe connectivity, the number shown represents the number of direct flights available between nodes in the network. A higher number denotes more direct, non-stop service, and therefore a higher degree of network connectivity. The number representing centralization is the number of in- and outbound shipment activities, by truck and air, at the busiest node. Again, a higher number represents a greater amount of centralization of activity at one node. Table IV-1 also lists the minimum objective function value, or total cost, for each solution, and a reference to the applicable network solution diagram in Figure 4-1.

Case I, or the basic network, yielded a solution which

TABLE IV-1

## TABLEAU OF EXPERIMENTAL RESULTS

	Conn *	Cent **	Cost \$	Solution Type No.
<u>CASE I</u>				
Base Network	4	2	848,292	1
Cost Sensitivity Analyses:				
Higher Terminal Costs	4	2	848,865	1
Lower Terminal Costs	4	2	847,718	1
Half Line Haul Truck Costs	4	2	839,741	1
With X-flights	6	3	875,742	2
<u>CASE II</u> (Experiment 1)				
Large Network	4	2	935,533	1
With X-flights	6	3	975,500	3
<u>CASE III</u> (Experiment 2)				
Isolated Node			(deleted)	
<u>CASE IV</u> (Experiment 3)				
Long Distance to Destination	4	5	1,476,000	4
Restriction of Large Planes	2	5	1,510,600	5
Restriction of Large Planes with X-flights	5	7	1,527,600	6
<u>CASE V</u> (Experiment 4)				
Tonnage Imbalance	4	2	1,098,771	1
<u>CASE VI</u> (Experiment 5)				
Inventory Shift	4	3	1,237,400	7

\*Connectivity = number of direct city pair air routes

\*\*Centralization = number of in- and outbound activities at  
the busiest node

used only direct city to local airport truck shipments and large plane airlifts from each airport directly to the destination node. The next three runs, which consist of the sensitivity analysis of this basic network, give exactly the same

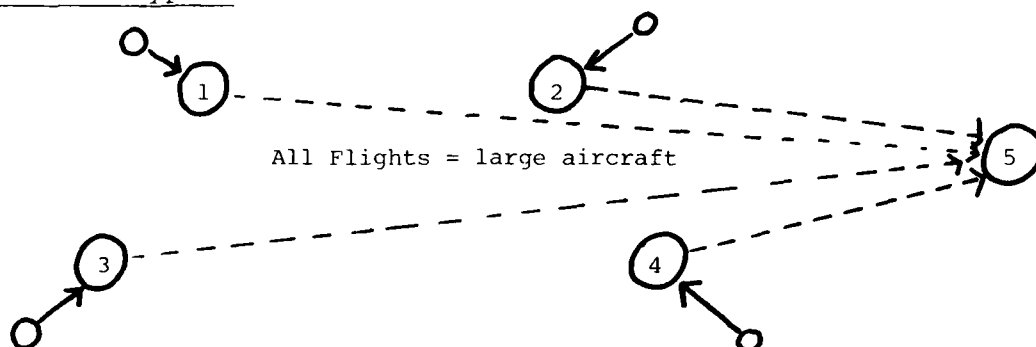
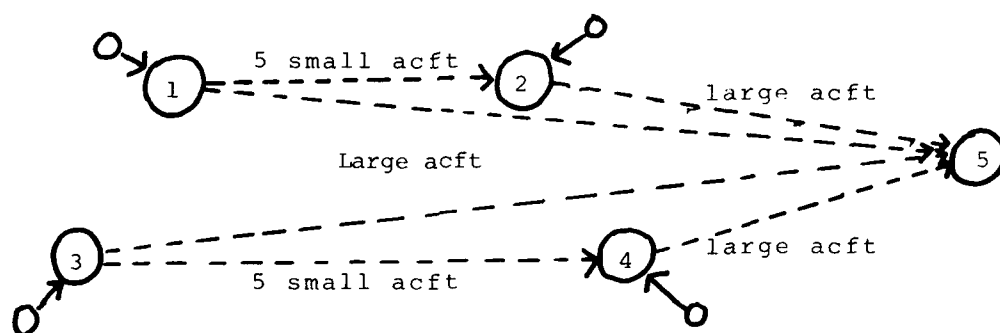
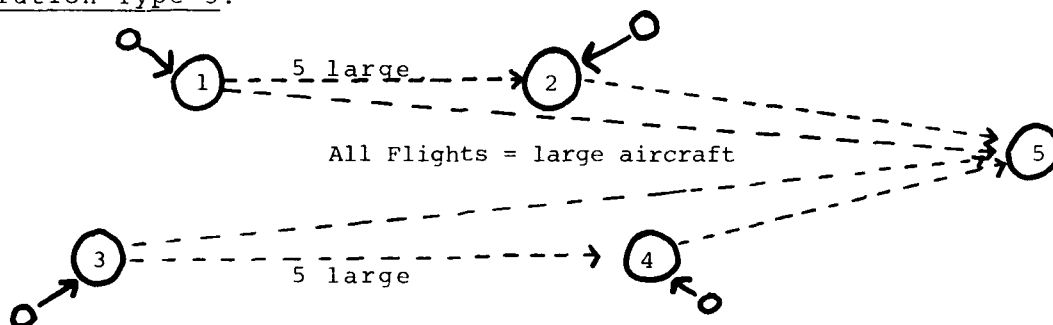
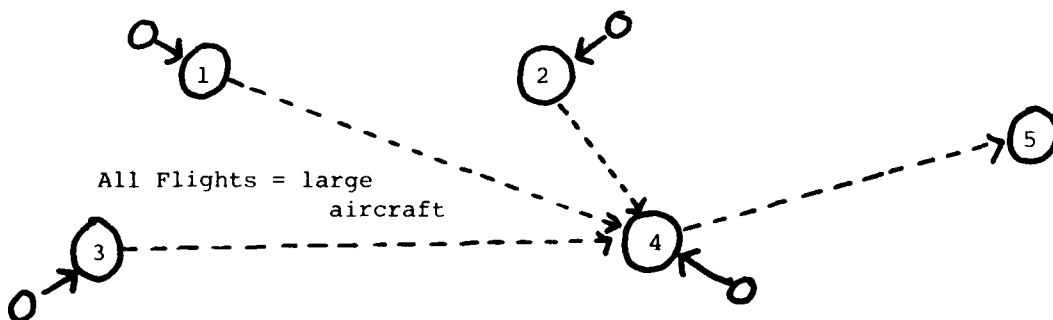
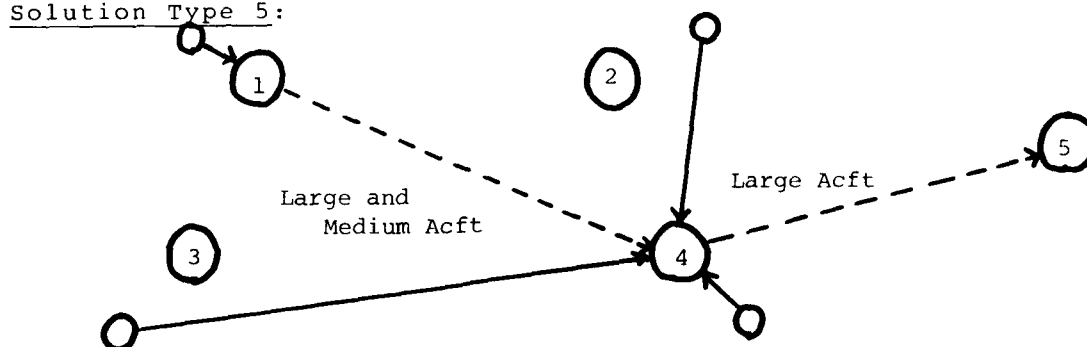
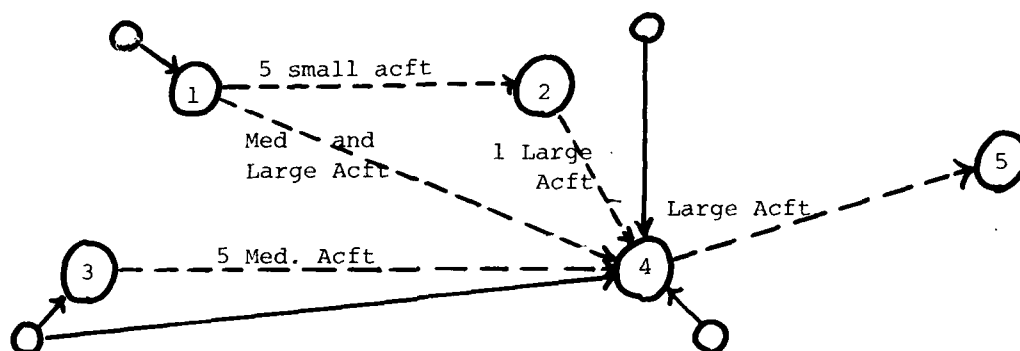
Solution Type 1:Solution Type 2:Solution Type 3:Solution Type 4:

Figure 4-1. Network Flows Resulting From Experiments

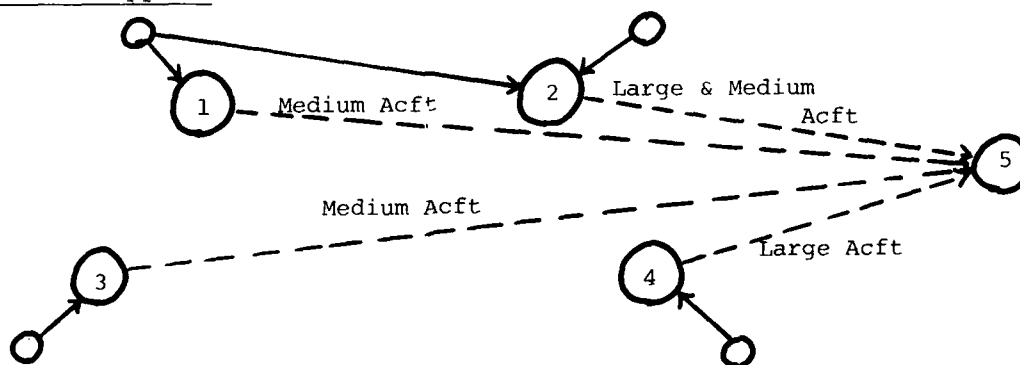
Solution Type 5:



Solution Type 6:



Solution Type 7:



----- Via Aircraft

~~\_\_\_\_\_~~ Via Truck

N

## Airports

0

Cities (Cargo Sources)

Figure 4-1. (Continued)

form of solution, at different costs. The terminal costs were varied to lower and upper bounds which were described by the 95% confidence intervals on the linear total cost function. The truck cost sensitivity was tested by halving the line haul cost per run with terminal costs set at \$40 per ton. It was felt that this reduction would better reflect a switch to a less costly intercity mode, such as Trailer on Flat Car (TOFC). None of these changes had any effect on the optimal flow pattern. For terminal costs, this result was predictable because they would have been incurred eventually, regardless of the airport to which the freight was trucked. There was no possibility that terminal costs would fall enough to lead to air carriage across the region, and transshipment to another plane. This was due to the availability of cheap movement via large freighters, with a cost savings much larger than potential terminal cost reductions.

The run labeled "Case I w/x flights" signifies the inclusion of a constraint demanding at least five direct flights from nodes 1 to 2 and 3 to 4. This represents the desire of a carrier to provide a minimum level of service between domestic city pairs. The resulting flows are notable in that small planes are used to satisfy this minimum service and to haul a small amount (100 tons) of cargo from 1 to 2 and 3 to 4. The cost of adding small plane runs within the region plus the cost of the additional transshipments at 2 and 4 is less than the cost of having five large planes simply

stop at 2 and 4 enroute to node 5. This solution was not motivated by lack of large aircraft, as significant slack remained in the large aircraft utilization constraint to satisfy this requirement.

Case II, or the first experiment, which represented an enlarged region, resulted in the same form of solution as described for the base network. However, when the requirement for the ten intra-regional flights was added, a third form of solution was generated. Here, ten large aircraft were diverted from direct flights from 1 to 5 and 3 to 5 to make stops at 2 and 4. With a larger region, the cost of an additional large plane landing and taking off was lower than that of adding small plane capacity. This is due to the small plane's relative inefficiency on longer flights.

Case III, or Experiment 2, was deleted from the program after inspection of the basic network solution. Since all cargo was moved by air out of the nodes, it was apparent that eliminating intercity surface transit for one node would have no effect on the optimal solution.

Case IV, or Experiment 3, produced three interesting solutions to the problem of long distance from region to destination. The basic experiment yielded solution type 4, in which trucks once again moved freight to local airports, then large planes carried it to node 4, and finally other large planes moved it across to node 5. Presumably the flights from nodes 1, 2 and 3 should have been flown with only a refueling stop at 4, but this was eliminated by the



Route Generator because the daily utilization would have been nearly 18 hours for these planes.

Variations on this experiment produced two additional solutions. When large planes were restricted to slightly more than the plane hours required to move cargo from 4 to 5, solution 5 resulted.<sup>2</sup> Here all cargo from nodes 2 and 3 was trucked to node 4, while the cargo from node 1, the farthest from node 4, was flown to node 4 on the remaining five large planes and eight medium planes. This produced the lowest connectivity and a moderate degree of centralization. The sensitivity analysis provided by MPOS showed that the decision to ship by medium plane or by surface mode would be highly sensitive to the relative costs of the modes, and that a 10% variation in these costs may have changed the optimal flow.

With large planes still restricted, the intra-regional flight requirement was added. As solution 6 depicts, this problem resulted in a variation of solution 5. The network showed both high connectivity and high centralization. Five small planes carried freight from 1 to 2 where it was transshipped to one large plane and carried to 4. Freight originating at 2 was trucked to 4. The minimum service requirement from 3 to 4 was flown by five medium planes, and the remaining cargo from 3 was trucked to 4. Once again this form of solution was shown to be highly sensitive to costs, particularly truck costs. A 10% increase in line haul truck costs would have led to air shipment from 2 to 4, while a 15% increase in local truck costs would have resulted in surface

carriage from 1 to 4. The least efficient aircraft used were the medium planes from 1 to 4. Had there been an additional eight hours of large plane time, large planes would have flown this cargo.

Case V, or Experiment 4, which analyzed the effects of tonnage imbalance, differed only in overall cost and number of large aircraft flown from the basic network solution. Once again, all flights were direct from local airport to destination.

The last experiment, run as Case VI, reduced the availability of large aircraft to 20% of its former amount. This test was designed to discover the optimal use of a limited large plane inventory. The result (solution type 7) showed that large planes were utilized on the shorter runs from 2 and 4 to node 5, while medium planes provided direct service from 1, 2 and 3 to node 5. Interestingly, about two-thirds of city 1's tonnage traveled by truck to node 2 while the rest was flown from the local airport to node 5. This example accentuates the instability of the optimal solution when line haul truck costs are compared with medium plane transport in the 200-300 mile range. Had the truck costs decreased less than \$2 per ton, surface shipments would have moved freight from 1 to 2 and 3 to 4. The medium planes were completely utilized in this case, while small planes were not efficient enough to enter into the basis.

To summarize the results of these experiments, it is apparent that for inter-regional movements large aircraft are

always preferable to small and medium aircraft. For longer intra-regional legs, such as from node 1 to node 4, large aircraft still have the advantage. But for shorter legs, small and medium aircraft are most efficient. Line haul trucking costs will generally restrict the use of trucks to local airport freight deliveries when large and medium aircraft are available. Some intercity surface movement occurs if small aircraft are the only alternative.

The imposition of minimum level of local service usually results in some cost to the network. This cost can be measured in the difference between the two objective function values. These additional flights should be performed by small aircraft to minimize cost, unless the alternative to these intra-regional flights is surface transport. In Case IV, medium planes moved freight from 3 to 4 when no large planes were available, but trucks rather than small planes moved the freight which exceeded the medium planes' capacity.

The solutions to the networks were generally stable, that is, not subject to change with small variations in parameters, especially regarding the basic network. Although few actual cases of multiple optima were observed, the imposition of minimum level of service criteria did lead to some choices among alternate routes which were nearly equal in cost. Some examples of this phenomenon were mentioned earlier.

The basic cases, with no restrictions on aircraft usage and level of service, tended to use large aircraft on more connected, less centralized networks. This is in contradiction

to some models which are based on overall travel time minimization. A fleet of larger aircraft must give a lower frequency of service than comparable capacity in smaller planes, therefore the cargo spends more time waiting for a flight. Connectivity and centralization did increase with the addition of minimum service constraints, but the only strong tendency toward a hub-type operation occurred in Case IV, when it was assisted by the addition of geographical constraints. Even though increasing returns to scale in terminal operations were not considered, some centralization into hubs did occur. This tendency could have been more pronounced had returns to scale been considered, but this remains a topic for further analysis.

It must be noted that these results apply only to the hypothetical network described here. Care must be exercised when drawing generalizations from any particular air freight network, especially from one constructed of a non-existent region using average transportation costs. Nevertheless, there are a few points which must be made regarding optimal flows in air freight networks.

The experimental results show a degree of interrelatedness among the surface, terminal and air phases of network operation. This relationship implies that system optimization affects the cost and routing of freight through the three sub-systems. Conversely, externally imposed cost and routing constraints such as increased service between regional city pairs will affect the optimal system performance.

Attempts by participants in the system to impose these external constraints are usually motivated by corporate optimization (profit maximization), but could lead to less than optimal performance for the entire system. Another source of externally generated constraints is economic regulation. The usefulness of this model to these two parties, who are not always pursuing overall system optimality, is as a tool with which to estimate the impact of their actions on system performance.

The results of these experiments show that modal choice between surface transport and medium aircraft is highly sensitive to the cost of these modes. This should demonstrate both to corporate rate makers and to economic regulators that costs imposed externally on one mode can significantly change the optimal network flows. For instance, in one case mentioned above, a 10% increase in truck costs would have led to the abandonment of truck service for air freight on that route. A model of this type could be useful in predicting specific instances of high sensitivity to modal costs.

This model is an initial attempt to describe a large, diverse system and it will probably not satisfy the particular needs of an analyst. In each of the three phases of operation there are constraints specific to that phase which would probably better describe the system. For instance, optimal truck and aircraft routing will depend on backhaul availability and maintenance locations. An air carrier's fleet composition will depend on capital and air frames available. These and

many other possibilities were omitted from this model for the sake of simplicity and flexibility. Despite these omissions and other simplifying assumptions, the model does select a minimum cost cargo path through the network, given somewhat realistic parameters. All the solutions reached during testing and experimentation were viable and intuitively appealing, although the need for more advanced experimentation is clearly indicated. Perhaps the most logical step would be to apply this package to an existing air freight region. This would not only test the validity of the underlying assumptions, but would also point the way toward the most productive modifications to the model.

## FOOTNOTES

### *Chapter I*

<sup>1</sup>Aviation Week and Space Technology, 13 March 1978, p. 146.

<sup>2</sup>Transportation Society of America, Transportation Facts and Trends, 13th Edition, Rev. April 1978, p. 3.

<sup>3</sup>R. E. Caves, Air Transport and Its Regulators (Harvard University Press, 1962), p. 434.

<sup>4</sup>D. F. Pegrum, Transportation: Economics and Public Policy (Irwin, 1963).

<sup>5</sup>W. A. Jordan, Airline Regulation in America: Effects and Imperfections (Johns Hopkins Press, 1970).

<sup>6</sup>T. E. Keeler, "Airline Regulation and Market Performance," Bell Journal of Economics and Management Science, Autumn 1972.

<sup>7</sup>Hearings Before the Subcommittee on Aviation of the Committee of Commerce, Science and Transportation, U. S. Senate, on S-292 and S-689, March 21-24, 1977.

Hearings on the Oversight of CAB Practices and Procedures, Senate Committee on the Judiciary, February and March, 1975.

<sup>8</sup>A. E. Kahn, Economics of Regulation, Principles and Institutions, Volume II.

Idem, Paper Presented at Northwestern University, Evanston, Illinois, 6 November 1977.

### *Chapter II*

<sup>1</sup>P. S. Smith, Air Freight Operations, Economics and Marketing (Faber and Faber, London, 1974).

<sup>2</sup>L. M. Schneider, The Future of the U. S. Domestic Air Freight Industry (Harvard Press, Boston, 1973).

<sup>3</sup>F. J. Stephenson, An Analysis and Evaluation of the Domestic Air Freight Forwarding Industry, Ph.D. Dissertation, University of Minnesota, 1975.

<sup>4</sup>W. B. Allen and L. N. Moses, "Choice of Mode in U. S. Overseas Trade," Transportation Review Forum, 1968.

<sup>5</sup>Schneider, op. cit.

<sup>6</sup>P. J. Fletcher, "Air Freight Has More to Offer Than Speed and Economy," Freight and Container Transportation, November 1972, pp. 26-32.

<sup>7</sup>F. R. Lineaweaver, "Tradeoffs in Shipping by Air," Distribution Worldwide, July 1971.

<sup>8</sup>A. G. Slater, "Advantages of Air Cargo Distribution in Perspective," International Journal of Physical Distribution, Volume 4, Number 1, 1973.

<sup>9</sup>"Costing the Air Freight Mode," Freight Management, April 1968, p. 45-46.

<sup>10</sup>Freight Management, August 1968, p. 63-65.

<sup>11</sup>J. D. Stites, "Cargo Terminal Analysis," Defense Transportation Journal, March - April, 1971.

<sup>12</sup>An Introduction to Air Freight Rates, Revised, U. S. Civil Aeronautics Board, Washington, D.C., November 1968.

<sup>13</sup>J. C. Miller III, "The Optimal Pricing of Freight in Combination Aircraft," Journal of Transport Economics and Policy, September 1973, pp. 258-268.

<sup>14</sup>G. R. Faulhaber, "Cross Subsidization: Pricing in Public Enterprises," American Economic Review, December 1975, pp. 966-977.

<sup>15</sup>"Flying the Snarled-Up Skies," Time, 3 July 1978, p. 61.

<sup>16</sup>International Air Transport Association, Airport Terminals Reference Manual, 6th Edition, December 1976.



<sup>17</sup>Hackney - Airlift Associates, Inc., Terminals for Air Cargo, April 1961.

<sup>18</sup>Smith, op. cit.

<sup>19</sup>Manalytics, Inc., Cargo Flows and Facility Requirements at the New Montreal International Airport, San Francisco, February 1973.

<sup>20</sup>Stites, op. cit.

<sup>21</sup>Construction Engineering Research Laboratory, Stochastic Network to Model an Air Cargo Terminal, Champaign, Il, 1973.

<sup>22</sup>F. L. Hitchcock, "The Distribution of a Product From Several Sources to Numerous Localities," Journal of Mathematical Physics 20, 1941, pp. 224-230.

<sup>23</sup>G. B. Dantzig, Linear Programming and Extensions, Chapter 28 (Princeton University Press, Princeton, New Jersey, 1963).

<sup>24</sup>R. W. Simpson, Scheduling and Routing Models for Air-line Systems (Massachusetts Institute of Technology, Cambridge, Ma., 1969), pp. 23-30.

<sup>25</sup>R. B. Fetter et al., Model for Design and Evaluation of Air Cargo Systems (Rand Corporation, Santa Monica, Ca., 1966).

<sup>26</sup>W. A. Jessiman and D. E. Ward, Intercity Transportation Effectiveness Model, Department of Transportation, 1970.

<sup>27</sup>S. Gordon and R. de Neufville, "Design of Air Transportation Networks," Transportation Research, September 1973, pp. 207-222.

### *Chapter III*

<sup>1</sup>A. F. Friedlaender, The Dilemma of Freight Transportation Regulation (Brookings Institute, Washington, D.C., 1969).

<sup>2</sup>C. Cohen and J. Stein, Multi-Purpose-Optimization-System, User's Guide (Northwestern University, Evanston, Il., 1974).

<sup>3</sup>Manalytics, Inc., op. cit.

<sup>4</sup>P. S. Smith, op. cit.

<sup>5</sup>Interview with: Director of Transportation, Military Airlift Command (MAC), USAF, Scott AFB, Il., 24 March 1978.

Interview with: Mr. Bill Thompson, Cargo Marketing, United Airlines, Cargo Division, Chicago, Il., 25 April 1978.

<sup>6</sup>L. Ott and W. Mendenhall, "Designs for Estimating the Slope of a Second Order Linear Model," Technometrica, Volume 14:2, May 1972.

#### *Chapter IV*

<sup>1</sup>It must be recognized that this shift from a quadratic programming model to a linear model detracts significantly from the long term applicability of this solution. Removing the quadratic term prohibits the consideration of any increasing returns to scale in terminal operations, unless an avoidable fixed cost per terminal is included. This type of solution would have involved the use of integer programming and branch-and-bound techniques to represent the complete closing of unused terminals. This method was rejected as being prohibitively expensive for this project, and a linear programming method was employed.

<sup>2</sup>Solution type 5 clearly demonstrates the problems created by the assumption that fixed terminal costs are unavoidable. Since terminals 2 and 3 are not used, the long term implication is that they would be closed, thus alleviating the fixed cost. Without using an integer programming solution, however, they do remain open, thus casting doubt upon the optimality of this solution for the long run.

## BIBLIOGRAPHY

### *I. Books*

- I. Casey Analysis Service. Industrial Location Theory in the Era of Super Cargo Aircraft. Falls Church, Va.: 1967.
- Caves, R. E. Air Transport and Its Regulators. Cambridge: Harvard University Press, 1962.
- Cohen, C. and Stein, J. Multi-Purpose-Optimization-System, User's Guide. Evanston: Northwestern University, 1974.
- Dantzig, G. B. Linear Programming and Extensions. Princeton: Princeton University Press, 1963.
- Fetter, R. B. et al. Model For Design and Evaluation of Air Cargo Systems. Cambridge: Massachusetts Institute of Technology, 1969.
- Friedlaender, A. D. The Dilemma of Freight Transport Regulation. Washington, D.C.: Brookings Institute, 1969.
- Gurel, M. and Winbigler, D. Container Provisioning for an Airline Network. Seattle: Boeing Co., 1967.
- Hackney - Airlift Associates, Inc. Terminals for Air Cargo. April 1961.
- Institute of Civil Engineers. World Airports, The Way Ahead. London: 1970.
- International Airline Transport Association. Economics of Air Cargo Carriage and Service. October 1969.
- \_\_\_\_\_. Airport Terminals Reference Manual, 6th Edition.
- Jordan, W. A. Airline Regulation in America: Effects and Imperfections. Johns Hopkins Press, 1970.
- Kahn, A. D., Economics of Regulation, Principles and Institutions. Volume II.
- Manalytics, Inc. Cargo Flows and Facility Requirements at the New Montreal International Airport. San Francisco: February 1973.

- Maurer, R. The Aeroplane, a Link in the Transport Chain. Institut du Transport Aérien. Paris: 1965.
- Pegrum, D. F. Transportation: Economics and Public Policy. Irwin, 1963.
- Schneider, L. M. The Future of the U. S. Domestic Air Freight Industry. Cambridge: Harvard University Press, 1973.
- Simpson, R. W. Scheduling and Routing Models for Airline Systems. Cambridge: Massachusetts Institute of Technology, 1969.
- Smith, P. S. Air Freight Operations, Economics and Marketing. London: Faber and Faber, 1974.
- Stephenson, F. J. An Analysis and Evaluation of the Domestic Air Freight Forwarding Industry, Ph.D. Dissertation. University of Minnesota, 1975.
- Transportation Society of America. Transportation Facts and Trends, 13th Edition, Rev. April 1978.

## II. Articles

- "Air Cargo, Overloading the Bandwagon," Interavia (April 1975), pp. 403-407.
- "Air Cargo - Nowhere to Go But Up," Via Port of New York - New Jersey (December 1977), pp. 2-5.
- Allen, W. B. and Moses, L. N. "Choice of Mode in U. S. Overseas Trade," Transportation Review Forum (1968).
- Aschenback, L. B. "Planning the Future Air Cargo System," Interavia (November 1967), p. 1751.
- Aviation Week and Space Technology (13 March 1978), p. 146.
- Barton, R. and Gumaer, R. "The Optimum Routing for an Air Cargo Carrier's Mixed Fleet," Transportation: A Service, New York: New York Academy of Science, 1967.
- "Costing the Air Freight Mode," Freight Management (April 1968), pp. 45-46.
- Faulhaber, G. R., "Cross Subsidization: Pricing in Public Enterprises," American Economic Review (December 1975), pp. 966-977.
- Fletcher, P. J. "Air Freight Has More to Offer Than Speed and Economy," Freight and Container Transportation (November 1972), pp. 26-32.

- Freight Management (August 1968), pp. 63-65.
- "Flying the Snarled-Up Skies," Time (3 July 1978), p. 61.
- Gilbert, J. et al. Logistics and Transportation Review, Vol. II, No. 2 (1974).
- Gordon, S. and de Neufville, R. "Design of Air Transportation Networks," Transportation Research (September 1973), pp. 207-222.
- Hitchcock, F. L. "The Distribution of a Product From Several Sources to Numerous Localities," Journal of Mathematical Physics 20 (1941), pp. 224-230.
- Keeler, T. E. "Airline Regulation and Market Performance," Bell Journal of Economics and Management Science (Autumn 1972).
- Lineaweaver, F. R. "Tradeoffs in Shipping By Air," Distribution Worldwide (July 1971).
- Miller III, J. C. "The Optimal Pricing of Freight in Combination Aircraft," Journal of Transport Economics and Policy (September 1973), pp. 258-268.
- Midler, J. and Wallmer, R. "Stochastic Program Models for Scheduling Airlift Operations," Naval Research Logistics Quarterly (September 1969), p. 315.
- Narodick, K. "Regulation and Competition in the Domestic Air Cargo Industry," Atlanta Economic Review (August 1971), pp. 18-28.
- Ott, L. and Mendenhall, W. "Designs for Estimating the Slope of a SEcond Order Linear Model," Technometrica, Vol. 14:2 (May 1972).
- Schneider, C. "American Asks Air Cargo Rate Related to Cost," Aviation Week and Space Technology (29 April 1974).
- Slater, A. G. "Advantages of Air Cargo Distribution in Perspective," International Journal of Physical Distribution, Vol. 4, No. 1 (1973).
- Stites, J. D. "Cargo Terminal Analysis," Defense Transportation Journal (March - April 1971).
- St. Mark, J. "Four Wheels Are Good, But Fixed Wings Are Better," Airport Services Management (March 1975), pp. 29-32.
- Wehrman, H., "Finding Cost-Minimal Cargo Routes," AGIFORS 14th Annual Symposium (1974).

III. Government Publications.

Civil Aeronautics Board. An Introduction to Air Freight Rates, Revised. Washington, D.C.: November 1968.

\_\_\_\_\_. Cargo Potential in Combination Aircraft. Washington, D.C.: 1974.

\_\_\_\_\_. Handbook of Airline Statistics. Washington, D.C.: 1976.

Construction Engineering Research Laboratory. Stochastic Network to Model an Air Cargo Terminal. Champaign, IL.: 1973.

Hearings Before the Subcommittee on Aviation of the Committee of Commerce, Science and Transportation, U. S. Senate, on S-292 and S-689. March 21-24, 1977.

Hearings on the Oversight of CAB Practices and Procedures, Senate Committee on the Judiciary, February and March, 1975.

Jessiman, W. A. and Ward, D. E. Intercity Transportation Effectiveness Model. Department of Transportation, 1970.

APPENDIX I

QUADRATIC PROGRAM

```

*****
*                                     *
*               M P O S               *
*                                     *
*             VERSION 4.0             *
*                                     *
* MULTI-PURPOSE OPTIMIZATION SYSTEM *
*                                     *
*****

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\* PROBLEM NUMBER 1 \*\*\*\*\*

## TITLE

AIR FREIGHT NETWORK CASE ONE (BASIC NETWORK)

## PREVISE

## VARIABLES

TT11 TO TT14 TT21 TO TT24 TT31 TO TT34 TT41 TO TT44 TA12 TO TA15 TA21 TA23 TA24  
 TA25 TA31 TA32 TA34 TA35 TA41 TO TA43 TA45  
 F101 TO F152 F201 TO F252 F301 TO F352  
 T0112 T1712 T1312 T1912 T2012 T2312 T3512 T4412  
 T0213 T1713 T2013 T2113 T2213 T2413 T2613 T4513  
 T0314 T1814 T2114 T2314 T2414 T2514 T2714 T3614  
 T0415 T1915 T2215 T2515 T2815 T3715 T4615  
 T0521 T2621 T2721 T2821 T2921 T3221 T3821 T4721  
 T0623 T1723 T2623 T2923 T3023 T3123 T3323 T4823  
 T0724 T1824 T2724 T3024 T3224 T3324 T3424 T3924  
 T0825 T1925 T2825 T3125 T3425 T4025 T4925  
 T0931 T2931 T3531 T3631 T3731 T3831 T4131 T5031  
 T1032 T2032 T3532 T3832 T3932 T4032 T4232 T5132  
 T1134 T2134 T3034 T3634 T3934 T4134 T4234 T4334  
 T1235 T2235 T3135 T3735 T4035 T4335 T5235  
 T1341 T2341 T4141 T4441 T4541 T4641 T4741 T5041  
 T1442 T2342 T4242 T4442 T4742 T4842 T4942 T5142  
 T1543 T2443 T3343 T4543 T4643 T5043 T5143 T5243  
 T1645 T2545 T3445 T4345 T4645 T4945 T5245

## MINIMIZE

49TT11+160TT12+160TT13+232TT14+  
 160TT21+49TT22+232TT23+160TT24+  
 160TT31+232TT32+49TT33+190TT34+  
 232TT41+160TT42+190TT43+49TT44+  
 2853F101+2853F102+3199F103+2853F105+3199F106+2853F107+2853F109+3199F110+  
 2997F111+3199F113+2853F114+2997F115+6052F117+5706F118+6052F120+5850F121+  
 6052F123+6197F124+5706F126+6052F127+6052F129+6197F130+6052F132+5850F133+  
 5706F135+6052F136+6052F138+6052F139+6197F141+5850F142+6052F144+6052F145+  
 5706F147+6052F148+5850F150+6197F151+  
 3655F201+3655F202+4063F203+16575F204+3655F205+4063F206+3655F207+15895F208+  
 3655F209+4063F210+3825F211+16575F212+4063F213+3655F214+3825F215+15725F216+  
 7718F217+7310F218+19550F219+7718F220+7480F221+20230F222+7718F223+7888F224+  
 19788F225+7310F226+7718F227+20230F228+7718F229+7888F230+20638F231+7718F232+  
 7460F233+19380F234+7310F235+7718F236+20230F237+7718F238+7718F239+19958F240+  
 7888F241+7480F242+19550F243+7718F244+7718F245+20638F246+7310F247+7718F248+  
 19550F249+7480F250+7888F251+20400F252+  
 4300F301+4300F302+4780F303+19500F304+4300F305+4780F306+4300F307+18700F308+  
 4300F309+4780F310+4500F311+19500F312+4780F313+4300F314+4500F315+18500F316+  
 9080F317+8600F318+23000F319+9080F320+8800F321+23800F322+9080F323+9280F324+



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 \* PROBLEM NUMBER 1 \*  
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USING PREVIOUS

AIR FREIGHT NETWORK CASE ONE (BASIC NETWORK)

23280F325+8600F326+9080F327+23800F328+9080F329+9280F330+24280F331+9080F332+  
 8500F333+22800F334+8600F335+9080F336+23800F337+9080F338+9080F339+23480F340+  
 9280F341+8800F342+23000F343+9080F344+9080F345+24280F346+8600F347+9080F348+  
 23000F349+8600F350+2280F351+24000F352+

16.41679TA12+

16.41679TA13+

16.41679TA14+

16.41679TA15+

16.41679TA21+

16.41679TA23+

16.41679TA24+

16.41679TA25+

16.41679TA31+

16.41679TA32+

16.41679TA34+

16.41679TA35+

16.41679TA41+

16.41679TA42+

16.41679TA43+

16.41679TA45

CONSTRAINTS

1. TT11+TT12+TT13+TT14.EQ.450
2. TT21+TT22+TT23+TT24.EQ.500
3. TT31+TT32+TT33+TT34.EQ.500
4. TT41+TT42+TT43+TT44.EQ.450
5. TA15+TA25+TA35+TA45.EQ.1900
6. TA21+TA31+TA41-TA12-TA13-TA14-TA15+TT11+TT21+TT31+TT41.EQ.0
7. TA12+TA32+TA42-TA21-TA23-TA24-TA25+TT22+TT12+TT32+TT42.EQ.0
8. TA13+TA23+TA43-TA31-TA32-TA34-TA35+TT33+TT13+TT23+TT43.EQ.0
9. TA14+TA24+TA34-TA41-TA42-TA43-TA45+TT44+TT14+TT24+TT34.EQ.0
10. T0112+T1712+T1812+T1912+T2012+T2312+T3512+T4412-TA12.EQ.0
11. T0213+T1713+T2013+T2113+T2213+T2413+T2613+T4513-TA13.EQ.0
12. T0314+T1814+T2114+T2314+T2414+T2514+T2714+T3614-TA14.EQ.0
13. T0415+T1915+T2215+T2515+T2815+T3715+T4615-TA15.EQ.0
14. T0521+T2621+T2721+T2821+T2921+T3221+T3821+T4721-TA21.EQ.0
15. T0623+T1723+T2623+T2923+T3023+T3123+T3323+T4823-TA23.EQ.0
16. T0724+T1824+T2724+T3024+T3224+T3324+T3424+T3924-TA24.EQ.0
17. T0825+T1925+T2625+T3125+T3425+T4025+T4925-TA25.EQ.0
18. T0931+T2931+T3531+T3631+T3731+T3831+T4131+T5031-TA31.EQ.0
19. T1032+T2032+T3532+T3832+T3932+T4032+T4232+T5132-TA32.EQ.0
20. T1134+T2134+T3034+T3634+T3934+T4134+T4234+T4334-TA34.EQ.0
21. T1235+T2235+T3135+T3735+T4035+T4335+T5235-TA35.EQ.0
22. T1341+T3241+T4141+T4441+T4541+T4641+T4741+T5041-TA41.EQ.0
23. T1442+T2342+T4242+T4442+T4742+T4842+T4942+T5142-TA42.EQ.0
24. T1543+T2443+T3343+T4543+T4643+T5043+T5143+T5243-TA43.EQ.0
25. T1645+T2545+T3445+T4345+T4645+T4945+T5245-TA45.EQ.0
26. T0112+T1712+T1713+T1812+T1814+T1912+T1915+T3532+T3512+T4442+T4412-  
 10F101-10F117-10F118-10F135-10F144-  
 25F201-25F217-25F218-25F219-25F235-25F244-

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PROBLEM NUMBER 1 \*  
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ING PRELIMED  
R FREIGHT NETWORK CASE ONE (BASIC NETWORK)

- 50F301-50F317-50F318-50F319-50F335-50F344.LE.0
27. T0213+T2013+T2012+T2113+T2114+T2213+T2215+T2623+T2613+T4543+T4513-  
10F102-10F120-10F121-10F126-10F145-  
25F202-25F220-25F221-25F222-25F226-25F245-  
50F302-50F320-50F321-50F322-50F326-50F345.LE.0
28. T0314+T2314+T2312+T2414+T2413+T2514+T2515+T2724+T2714+T3634+T3614-  
10F103-10F123-10F124-10F127-10F136-  
25F203-25F223-25F224-25F225-25F227-25F236-  
50F303-50F323-50F324-50F325-50F327-50F336.LE.0
29. T0415+T2825+T2815+T3735+T3715+T4645+T4615-  
25F204-25F228-25F237-25F246-50F304-50F328-50F337-50F346.LE.0
30. T0521+T2621+T2623+T2721+T2724+T2821+T2825+T3631+T3621+T4741+T4721-  
10F105-10F126-10F127-10F138-10F147-  
25F205-25F226-25F227-25F228-25F238-25F247-  
50F305-50F326-50F327-50F328-50F338-50F347.LE.0
31. T0623+T1713+T1723+T2923+T2921+T3023+T3024+T3123+T3125+T4843+T4823-  
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25F206-25F217-25F229-25F230-25F231-25F246-  
50F306-50F317-50F329-50F330-50F331-50F348.LE.0
32. T0724+T1814+T1824+T3224+T3221+T3324+T3323+T3424+T3425+T3934+T3924-  
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25F207-25F218-25F232-25F233-25F234-25F239-  
50F307-50F318-50F332-50F333-50F334-50F339.LE.0
33. T1915+T0825+T1925+T4035+T4025+T4945+T4925-  
25F208-25F219-25F240-25F249-50F308-50F319-50F340-50F349.LE.0
34. T0931+T2921+T2931+T3531+T3532+T3631+T3634+T3731+T3735+T5041+T5031-  
10F109-10F129-10F135-10F136-10F150-  
25F209-25F229-25F235-25F236-25F237-25F250-  
50F309-50F329-50F335-50F336-50F337-50F350.LE.0
35. T1032+T2012+T2032+T3832+T3831+T3932+T3934+T4032+T4035+T5142+T5132-  
10F110-10F120-10F138-10F139-10F151-  
25F210-25F220-25F238-25F239-25F240-25F251-  
50F310-50F320-50F338-50F339-50F340-50F351.LE.0
36. T1134+T2114+T2134+T3024+T3034+T4134+T4131+T4234+T4232+T4334+T4335-  
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25F211-25F221-25F230-25F241-25F242-25F243-  
50F311-50F321-50F330-50F341-50F342-50F343.LE.0
37. T1235+T2215+T2235+T3125+T3135+T5245+T5235-  
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38. T1341+T3221+T3241+T4131+T4141+T4441+T4442+T4541+T4543+T4641+T4645-  
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25F213-25F232-25F241-25F244-25F245-25F246-  
50F313-50F332-50F341-50F344-50F345-50F346.LE.0
39. T1442+T2312+T2342+T4232+T4242+T4742+T4741+T4842+T4843+T4942+T4945-  
10F114-10F123-10F142-10F147-10F148-  
25F214-25F223-25F242-25F247-25F248-25F249-  
50F314-50F323-50F342-50F347-50F348-50F349.LE.0
40. T1543+T2413+T2443+T3323+T3343+T5043+T5041+T5143+T5142+T5243+T5245-  
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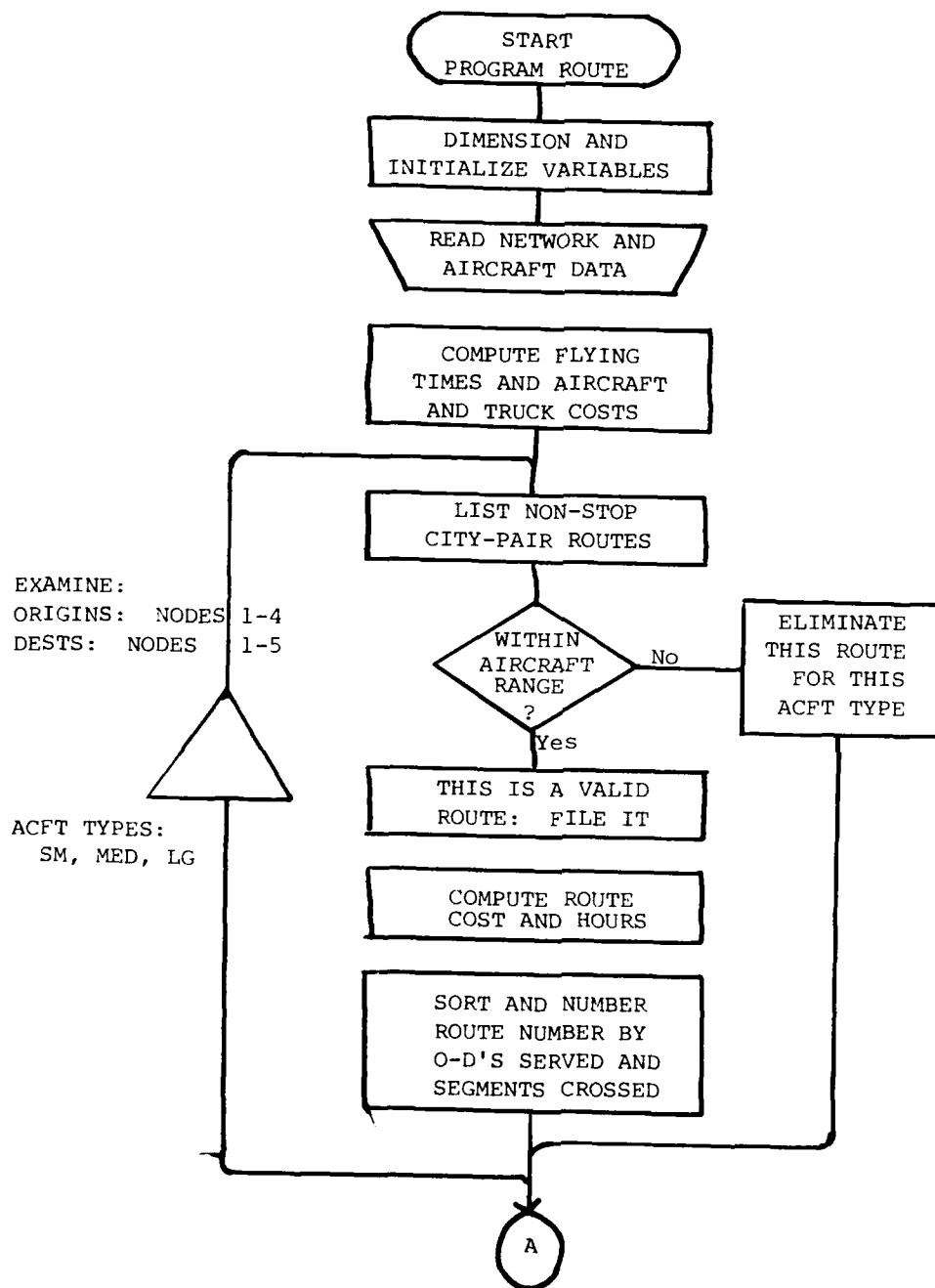
\*\*\*\*\*  
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\*\*\*\*\*

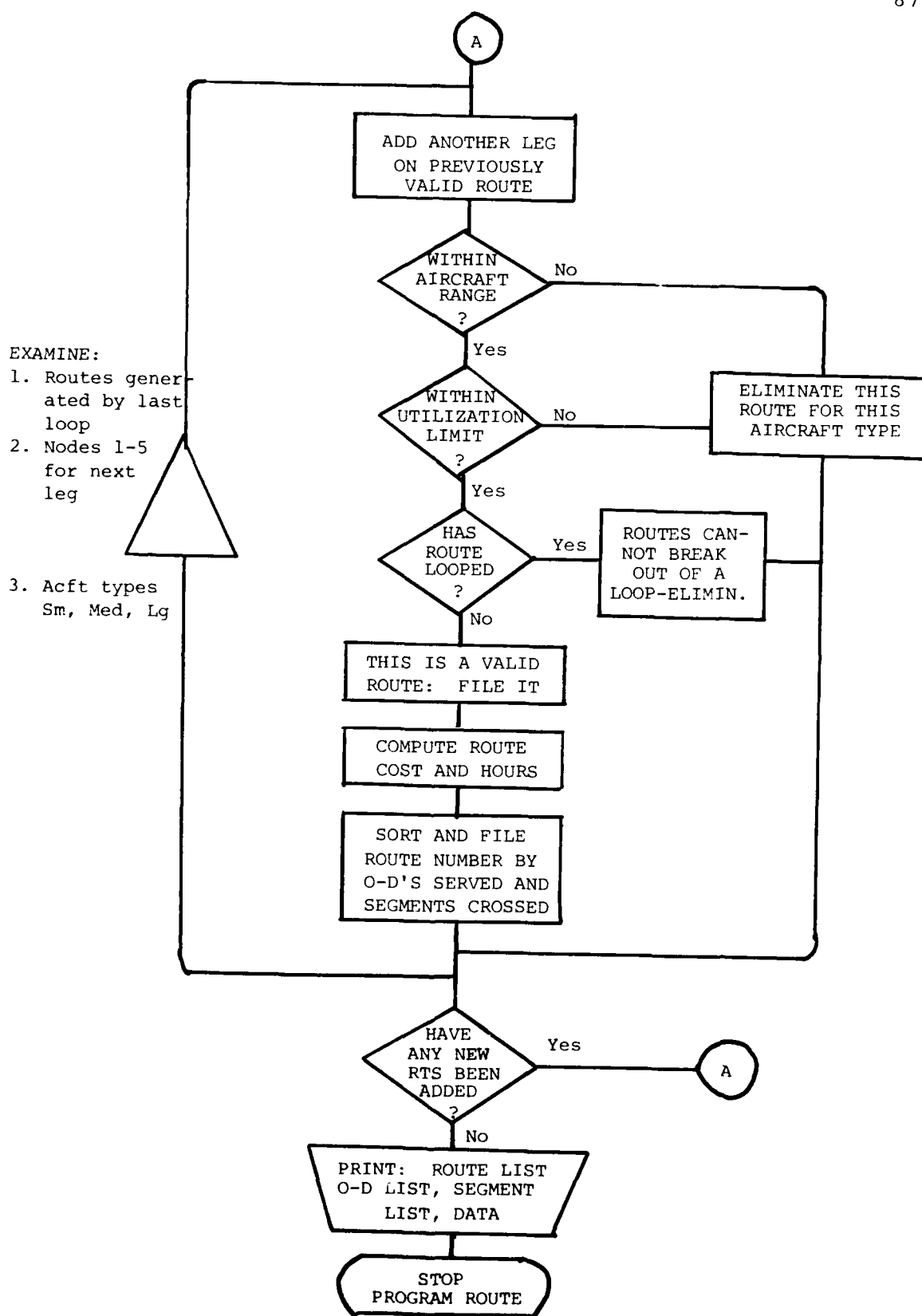
PREVISED  
EIGHT NETWORK CASE ONE (BASIC NETWORK)

25F215-25F224-25F233-25F250-25F251-25F252-  
50F315-50F324-50F333-50F350-50F351-50F352.LE.0  
T2515+T2545+T1645+T3425+T3445+T4335+T4345-  
25F216-25F225-25F234-25F243-50F316-50F325-50F334-50F343.LE.0  
1.9F101+1.9F102+2.2F103+1.9F105+2.2F106+1.9F107+1.9F109+2.2F110+2.1F111+2.2F113  
1.9F114+2.1F115+4.2F117+3.9F118+4.2F120+4.0F121+4.2F123+4.3F124+3.9F126+4.2F127  
4.2F129+4.3F130+4.2F132+4.0F133+3.9F135+4.2F136+4.2F138+4.2F139+4.3F141+4.0F142  
4.2F144+4.2F145+3.9F147+4.2F148+4.0F150+4.3F151.LE.500  
1.9F201+1.9F202+2.1F203+9.5F204+1.9F205+2.1F206+1.9F207+9.1F208+1.9F209+2.1F210  
2.0F211+9.5F212+2.1F213+1.9F214+2.0F215+9.0F216+4.0F217+3.8F218+11.0F219+  
4.0F220+3.9F221+11.4F222+4.0F223+4.1F224+11.1F225+3.8F226+4.0F227+11.4F228+  
4.0F229+4.1F230+11.0F231+4.0F232+3.9F233+10.9F234+3.8F235+4.0F236+11.4F237+  
4.0F238+4.0F239+11.2F240+4.1F241+3.9F242+11.0F243+4.0F244+4.0F245+11.6F246+  
3.8F247+4.0F248+11.0F249+3.9F250+4.1F251+11.5F252.LE.500  
1.90F301+1.90F302+2.14F303+9.50F304+1.90F305+2.14F306+1.90F307+9.10F308+  
1.90F309+2.14F310+2.00F311+9.50F312+2.14F313+2.00F315+9.00F316+4.04F317+  
3.80F318+11.0F319+4.04F320+3.90F321+11.4F322+4.04F323+4.14F324+11.14F325+  
3.80F326+4.04F327+11.4F328+4.04F329+4.14F330+11.64F331+4.04F332+3.90F333+  
10.9F334+3.8F335+4.04F336+11.4F337+4.04F338+4.04F339+11.24F340+4.14F341+  
3.90F342+11.0F343+4.04F344+4.04F345+11.64F346+3.80F347+4.04F348+11.0F349+  
3.90F350+4.14F351+11.5F352+1.9F314.LE.500  
RNGOBS  
RNGRHS  
OPTIMIZE

APPENDIX II

FORTTRAN ROUTE GENERATOR





MNF,U,B,T,R=1,I=INPUT,P=5000,E=2,.

```

PROGRAM ROUTE (INPUT,OUTPUT,TAPE4=INPUT,TAPE5=OUTPUT)
DIMENSION FTIM(5,5,3),FCST(5,5,3),RTS(900,6,3),HRS(900,3)
DIMENSION COST(900,3),UTMAX(3),RNGMX(3),FX(3),DOC(3),SPD(3)
DIMENSION DIST(5,5),TCST(5,5)
DIMENSION NSEG(5,5,100),NOD(5,5,100),INSEG(5,5),INOD(5,5)
DIMENSION IVDX(5,5),IVST(5,5,100)
DATA IVDX/25*1/IVST/2500*0/ MAXIV/0/
DATA RTS/16200*0.0/ICOUNT/0/
DATA NSEG/2500*0/NOD/2500*0/INSEG/25*1/INOD/25*1/
DATA INOMX,INSMX/2*0/
READ(4,100) UTMAX,RNGMX,FX,DOC,SPD
READ(4,101) DIST
100 FORMAT(5(3F10.4/))
101 FORMAT(16F5.1)
ICOL = 2
IROW = 1
DO 230 IX = 1,5
DO 230 IY = 1,5
TCST(IX,IY) = (DIST(IX,IY)*.6) + 40
IF(IX.EQ.IY) TCST(IX,IY) = 49
IF(IX.EQ.5) TCST(IX,IY) = 999999999
IF(IY.EQ.5) TCST(IX,IY) = 999999999
DO 230 IZ = 1,3
FTIM(IX,IY,IZ) = DIST(IX,IY)/SPD(IZ)+1.5
FCST(IX,IY,IZ) = FTIM(IX,IY,IZ) * DOC(IZ) + FX(IZ)
IF(DIST(IX,IY).LE.RNGMX(IZ)) GO TO 230
FTIM(IX,IY,IZ) = 99
230 CONTINUE
DO 200 J = 1,4
DO 200 I2 = 1,5
DO 212 IAC = 1,3
GOTCHA = 0
RTS(IROW,1,IAC) = J
IF(I2.EQ.J) GO TO 212
IF ( FTIM(J,I2,IAC) .GT. UTMAX(IAC)) GO TO 212
IF(FTIM(J,I2,IAC).EQ. 99) GO TO 212
GOTCHA = 1
RTS(IROW,ICOL,IAC) = I2
HRS(IROW,IAC) = FTIM(J,I2,IAC)
COST(IROW,IAC) = FCST(J,I2,IAC)
NSEG(J,I2,1) = IROW
INSEG(J,I2) = 2
NOD(J,I2,1) = IROW
INOD(J,I2) = 2
IVST(J,I2,1) = 100*IROW + 10*J + I2
IVDX(J,I2) = 2
212 CONTINUE
IF(GOTCHA.EQ.0) GO TO 200
IROW = IROW + 1
200 CONTINUE
INIT = 1
1 INIT2 = IROW
NDX = IROW-1
ICOL = ICOL + 1
ICLST = ICOL - 1
DO 201 K = INIT,NDX
DO 201 L = 1,5
DO 213 IAD = 1,3
CATCH = 0
LAST = RTS(K,ICLST,IAD)
IF (LAST.EQ.0) GO TO 213
DO 204 LL = 1,ICLST
IF(L.EQ. RTS(K,LL,IAD)) GO TO 213
204 CONTINUE
IF (FTIM(LAST,L,IAD).EQ.99) GO TO 213
HOURS = FTIM(LAST,L,IAD) + HRS(K,IAD)
IF (HOURS.GT. UTMAX(IAD)) GO TO 213
RTS(IROW,ICOL,IAD) = L
CATCH = 1
HRS(IROW,IAD) = HOURS
COST(IROW,IAD) = COST(K,IAD)+FCST(LAST,L,IAD)
DO 202 KK = 1,ICLST
RTS(IROW,KK,IAD) = RTS(K,KK,IAD)
202 CONTINUE

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```

IF(ICOUNT.EQ.IROW) GO TO 213
DO 206 MO = 1,ICLST
MOM = MO + 1
DO 206 IMM = MOM,ICOL
IDES = RTS(IROW,IMM,IAD)
IOR = RTS(IROW,MO,IAD)
INO = INOD(IOR,IDES)
NOD(IOR,IDES,INO) = IROW
INOD(IOR,IDES) = INOD(IOR,IDES) + 1
IF(INOD(IOR,IDES).GT.INOMX) INOMX = INOD(IOR,IDES)
206 CONTINUE
ICOUNT = IROW
213 CONTINUE
IF(CATCH.EQ.0) GO TO 201
DO 205 M = 1,ICLST
MM = M+1
II = RTS(IROW,M,3)
IJ = RTS(IROW,MM,3)
INS = INSEG(II,IJ)
NSEG(II,IJ,INS) = IROW
INSEG(II,IJ) = INSEG(II,IJ) + 1
IF(INSEG(II,IJ).GT.INSMX) INSMX = INSEG(II,IJ)
DO 208 MV = 1,M
DO 208 MVV = MM,ICOL
IY = RTS(IROW,MV,3)
IZ = RTS(IROW,MVV,3)
IVX = IVDX(II,IJ)
IVST(II,IJ,IVX) = 10C*IROW+10*IY+IZ
IVOX(II,IJ) = IVDX(II,IJ) + 1
IF(IVDX(II,IJ).GT.MAXIV) MAXIV = IVDX(II,IJ)
208 CONTINUE
205 CONTINUE
IROW = IROW + 1
201 CONTINUE
IF(INIT2.EQ.IROW) GO TO 2
INIT = INIT2
GO TO 1
2 WRITE(5,111)
WRITE(5,103) UTMX
WRITE(5,112)
WRITE(5,103) RNGMX
WRITE(5,113)
WRITE(5,104) FTIM
WRITE(5,114)
WRITE(5,104) FCST
WRITE(5,115)
WRITE(5,104) TCST
WRITE(5,105)
DO 203 IK=1,IROW
WRITE(5,106) IK,RTS(IK,1,3),RTS(IK,2,3),RTS(IK,3,3),RTS(IK,4,3),
1 RTS(IK,5,3),RTS(IK,6,3),HRS(IK,1),COST(IK,1),HRS(IK,2),COST(IK,2),
2 HRS(IK,3),COST(IK,3)
203 CONTINUE
WRITE(5,107)
107 FORMAT(* ROUTES SERVING THE FOLLOWING SEGMENTS*/ * 1-2 1-3 1-4
1 1-5 2-1 2-3 2-4 2-5 3-1 3-2 3-4 3-5 4-1 4-2
2 4-3 4-5*)
DO 231 IPS = 1,INSMX
WRITE(5,108) NSEG(1,2,IPS),NSEG(1,3,IPS),NSEG(1,4,IPS),NSEG(1,5,
1 IPS),NSEG(2,1,IPS),NSEG(2,3,IPS),NSEG(2,4,IPS),NSEG(2,5,IPS),
2 NSEG(3,1,IPS),NSEG(3,2,IPS),NSEG(3,4,IPS),NSEG(3,5,IPS),NSEG(4,1,
3 IPS),NSEG(4,2,IPS),NSEG(4,3,IPS),NSEG(4,5,IPS)
231 CONTINUE
WRITE(5,109)
109 FORMAT(* ROUTES SERVING THE FOLLOWING O-D PRS */ * 1-2 1-3 1-4
1 1-5 2-1 2-3 2-4 2-5 3-1 3-2 3-4 3-5 4-1 4-2
2 4-3 4-5*)
DO 232 IPO = 1,INOMX
WRITE(5,110) NOD(1,2,IPO),NOD(1,3,IPO),NOD(1,4,IPO),NOD(1,5,IPO),
2 NOD(2,1,IPO),NOD(2,3,IPO),NOD(2,4,IPO),NOD(2,5,IPO),NOD(3,1,IPO),
3 NOD(3,2,IPO),NOD(3,4,IPO),NOD(3,5,IPO),NOD(4,1,IPO),NOD(4,2,IPO),
4 NOD(4,3,IPO),NOD(4,5,IPO)
232 CONTINUE

```



```

WRITE (5,117)
DO 209 IQ = 1,MAXIV
WRITE(5,116) IVST(1,2,IQ),IVST(1,3,IQ),IVST(1,4,IQ),IVST(1,5,IQ),
1 IVST(2,1,IQ),IVST(2,3,IQ),IVST(2,4,IQ),IVST(2,5,IQ),IVST(3,1,IQ),
2 IVST(3,2,IQ),IVST(3,4,IQ),IVST(3,5,IQ),IVST(4,1,IQ),IVST(4,2,IQ),
3 IVST(4,3,IQ),IVST(4,5,IQ)
209 CONTINUE
103 FORMAT (3(5X,F10.3))
104 FORMAT (5(5X,F10.3))
105 FORMAT (*1 RTE. NO. STOPS ON ROUTE SM AC, HRS-COST MED AC, HRS
1-COST LG AC, HRS-COST *)
106 FORMAT (1X,I3,,5X 6F2.0, 4X, 3(2X,F5.2,2X F9.1))
108 FORMAT (16(I4,2X))
110 FORMAT (16(I4,2X))
111 FORMAT (// *1 MAX UTILIZATION OF ACFT, HRS/DAY */)
112 FORMAT (// * MAX RANGE OF ACFT, NON-STOP, HOURS */)
113 FORMAT (// * FLYING TIME BETWEEN AIRPORTS, SM, MED LG ACFT */)
114 FORMAT (// * COST OF FLYING SEGMENTS, SM, MED, LG ACFT */)
115 FORMAT (// * TRUCKING COSTS, CITIES TO AIRPORTS */)
116 FORMAT (1X, 16(I4,2X))
117 FORMAT (*10-D ROUTES BY SEGMENT*//)
STOP
END

```

AIK FORCE INST OF TECH WRIGHT-PATTERSON AFB OH F/G 15/5  
ANALYSIS OF THE CONNECTIVITY AND CENTRALIZATION OF REGIONAL AIR--ETC (11)  
AUG 78 P W RUSSO  
AFIT-CI-79-169T

F/G 15/5  
AIR--ETC (11)

UNCLASSIFIED

NL

222

Figure 10

END  
DATE  
FILMED  
1-80  
DTIC

## MAX UTILIZATION OF ACFT, HRS/DAY

12.000	12.000	12.000
--------	--------	--------

## MAX RANGE OF ACFT, NON-STOP, HOURS MILES

2000.000	5000.000	7000.000
----------	----------	----------

## FLYING TIME BETWEEN AIRPORTS, SM, MED LG ACFT

1.500	1.944	1.944	2.211	99.000
1.944	1.500	2.211	1.944	99.000
1.944	2.211	1.500	2.056	99.000
2.211	1.944	2.056	1.500	99.000
99.000	99.000	99.000	99.000	1.500
1.500	1.900	1.900	2.140	9.500
1.900	1.500	2.140	1.900	9.100
1.900	2.140	1.500	2.000	9.500
2.140	1.900	2.000	1.500	9.000
9.500	9.100	9.500	9.000	1.500
1.500	1.900	1.900	2.140	9.500
1.900	1.500	2.140	1.900	9.100
1.900	2.140	1.500	2.000	9.500
2.140	1.900	2.000	1.500	9.000
9.500	9.100	9.500	9.000	1.500

## COST OF FLYING SEGMENTS, SM, MED, LG ACFT

2275.000	2852.778	2852.778	3199.444	13830.556
2852.778	2275.000	3199.444	2852.778	13252.778
2852.778	3199.444	2275.000	2997.222	13830.556
3199.444	2852.778	2997.222	2275.000	13108.333
13830.556	13252.778	13830.556	13108.333	2275.000
2975.000	3655.000	3655.000	4063.000	16575.000
3655.000	2975.000	4063.000	3655.000	15895.000
3655.000	4063.000	2975.000	3825.000	16575.000
4063.000	3655.000	3825.000	2975.000	15725.000
16575.000	15895.000	16575.000	15725.000	2975.000
3500.000	4300.000	4300.000	4780.000	19500.000
4300.000	3500.000	4780.000	4300.000	18700.000
4300.000	4780.000	3500.000	4500.000	19500.000
4780.000	4300.000	4500.000	3500.000	18500.000
19500.000	18700.000	19500.000	18500.000	3500.000

## TRUCKING COSTS, CITIES TO AIRPORTS

49.000	160.000	160.000	232.000	* .999E+09
160.000	49.000	232.000	160.000	* .999E+09
160.000	232.000	49.000	190.000	* .999E+09
232.000	160.000	190.000	49.000	* .999E+09
* .999E+09	* .999E+09	* .999E+09	* .999E+09	* .999E+09

RTE. NO.	STOPS ON ROUTE	SM AC, HRS-COST	MED AC, HRS-COST	LG AC, HRS-COST
1	1.2. 0 0 0 0	1.94 2852.8	1.90 3655.0	1.90 4300.0
2	1.3. 0 0 0 0	1.94 2852.8	1.90 3655.0	1.90 4300.0
3	1.4. 0 0 0 0	2.21 3199.4	2.14 4063.0	2.14 4780.0
4	1.5. 0 0 0 0	I I	9.50 16575.0	9.50 19500.0
5	2.1. 0 0 0 0	1.94 2852.8	1.90 3655.0	1.90 4300.0
6	2.3. 0 0 0 0	2.21 3199.4	2.14 4063.0	2.14 4780.0
7	2.4. 0 0 0 0	1.94 2852.8	1.90 3655.0	1.90 4300.0
8	2.5. 0 0 0 0	I I	9.10 15895.0	9.10 18700.0
9	3.1. 0 0 0 0	1.94 2852.8	1.90 3655.0	1.90 4300.0
10	3.2. 0 0 0 0	2.21 3199.4	2.14 4063.0	2.14 4780.0
11	3.4. 0 0 0 0	2.06 2997.2	2.00 3825.0	2.00 4500.0
12	3.5. 0 0 0 0	I I	9.50 16575.0	9.50 19500.0
13	4.1. 0 0 0 0	2.21 3199.4	2.14 4063.0	2.14 4780.0
14	4.2. 0 0 0 0	1.94 2852.8	1.90 3655.0	1.90 4300.0
15	4.3. 0 0 0 0	2.06 2997.2	2.00 3825.0	2.00 4500.0
16	4.5. 0 0 0 0	I I	9.00 15725.0	9.00 18500.0
17	1.2.3. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
18	1.2.4. 0 0 0	3.89 5705.6	3.80 7310.0	3.80 8600.0
19	1.2.5. 0 0 0	I I	11.00 19550.0	11.00 23000.0
20	1.3.2. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
21	1.3.4. 0 0 0	4.00 5850.0	3.90 7480.0	3.90 8800.0
22	1.3.5. 0 0 0	I I	11.40 20230.0	11.40 23800.0
23	1.4.2. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
24	1.4.3. 0 0 0	4.27 6196.7	4.14 7888.0	4.14 9280.0
25	1.4.5. 0 0 0	I I	11.14 19788.0	11.14 23280.0
26	2.1.3. 0 0 0	3.89 5705.6	3.80 7310.0	3.80 8600.0
27	2.1.4. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
28	2.1.5. 0 0 0	I I	11.40 20230.0	11.40 23800.0
29	2.3.1. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
30	2.3.4. 0 0 0	4.27 6196.7	4.14 7888.0	4.14 9280.0
31	2.3.5. 0 0 0	I I	11.64 20638.0	11.64 24280.0
32	2.4.1. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
33	2.4.3. 0 0 0	4.00 5850.0	3.90 7480.0	3.90 8800.0
34	2.4.5. 0 0 0	I I	10.90 19380.0	10.90 22800.0
35	3.1.2. 0 0 0	3.89 5705.6	3.80 7310.0	3.80 8600.0
36	3.1.4. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
37	3.1.5. 0 0 0	I I	11.40 20230.0	11.40 23800.0
38	3.2.1. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
39	3.2.4. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
40	3.2.5. 0 0 0	I I	11.24 19958.0	11.24 23480.0
41	3.4.1. 0 0 0	4.27 6196.7	4.14 7888.0	4.14 9280.0
42	3.4.2. 0 0 0	4.00 5850.0	3.90 7480.0	3.90 8800.0
43	3.4.5. 0 0 0	I I	11.00 19550.0	11.00 23000.0
44	4.1.2. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
45	4.1.3. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
46	4.1.5. 0 0 0	I I	11.64 20638.0	11.64 24280.0
47	4.2.1. 0 0 0	3.89 5705.6	3.80 7310.0	3.80 8600.0
48	4.2.3. 0 0 0	4.16 6052.2	4.04 7718.0	4.04 9080.0
49	4.2.5. 0 0 0	I I	11.00 19550.0	11.00 23000.0
50	4.3.1. 0 0 0	4.00 5850.0	3.90 7480.0	3.90 8800.0
51	4.3.2. 0 0 0	4.27 6196.7	4.14 7888.0	4.14 9280.0
52	4.3.5. 0 0 0	I I	11.50 20400.0	11.50 24000.0
53	1.2.3.4. 0 0	6.21 9049.4	6.04 11543.0	6.04 13580.0
54	1.2.4.3. 0 0	5.94 8782.8	5.80 11135.0	5.80 13100.0

55	1.3.2.4.	0 0	6.10	8905.0	5.94	11373.0	5.94	13380.0
56	1.3.4.2.	0 0	5.94	8702.8	5.80	11135.0	5.80	13100.0
57	1.4.2.3.	0 0	6.37	9251.7	6.18	11781.0	6.18	13860.0
58	1.4.3.2.	0 0	6.48	9396.1	6.28	11951.0	6.28	14060.0
59	2.1.3.4.	0 0	5.94	8702.8	5.80	11135.0	5.80	13100.0
60	2.1.4.3.	0 0	6.21	9049.4	6.04	11543.0	6.04	13580.0
61	2.3.1.4.	0 0	6.37	9251.7	6.18	11781.0	6.18	13860.0
62	2.3.4.1.	0 0	6.48	9396.1	6.28	11951.0	6.28	14060.0
63	2.4.1.3.	0 0	6.10	8905.0	5.94	11373.0	5.94	13380.0
64	2.4.3.1.	0 0	5.94	8702.8	5.80	11135.0	5.80	13100.0
65	3.1.2.4.	0 0	5.83	8558.3	5.70	10965.0	5.70	12900.0
66	3.1.4.2.	0 0	6.10	8905.0	5.94	11373.0	5.94	13380.0
67	3.2.1.4.	0 0	6.37	9251.7	6.18	11781.0	6.18	13860.0
68	3.2.4.1.	0 0	6.37	9251.7	6.18	11781.0	6.18	13860.0
69	3.4.1.2.	0 0	6.21	9049.4	6.04	11543.0	6.04	13580.0
70	3.4.2.1.	0 0	5.94	8702.8	5.80	11135.0	5.80	13100.0
71	4.1.2.3.	0 0	6.37	9251.7	6.18	11781.0	6.18	13860.0
72	4.1.3.2.	0 0	6.37	9251.7	6.18	11781.0	6.18	13860.0
73	4.2.1.3.	0 0	5.83	8558.3	5.70	10965.0	5.70	12900.0
74	4.2.3.1.	0 0	6.10	8905.0	5.94	11373.0	5.94	13380.0
75	4.3.1.2.	0 0	5.94	8702.8	5.80	11135.0	5.80	13100.0
76	4.3.2.1.	0 0	6.21	9049.4	6.04	11543.0	6.04	13580.0
77	0 0 0 0 0 0		I	I	I	I	I	I

ROUTES SERVING THE FOLLOWING SEGMENTS

1-2	1-3	1-4	1-5	2-1	2-3	2-4	2-5	3-1	3-2	3-4	3-5	4-1	4-2	4-3	4-5
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17	20	23	28	26	17	18	19	29	20	21	22	32	23	24	25
18	21	24	37	27	29	32	40	35	38	30	31	41	42	33	34
19	22	25	46	28	30	33	49	36	39	41	52	44	47	50	43
35	26	27	0	38	31	34	0	37	40	42	0	45	48	51	0
44	45	36	8	47	48	39	0	50	51	43	0	46	49	52	0
53	55	57	0	59	53	54	0	61	55	53	0	62	56	54	0
54	56	58	0	60	57	55	0	64	58	56	0	63	57	58	0
65	59	68	0	67	61	63	0	65	67	59	0	68	66	60	0
69	63	61	0	70	62	64	0	66	68	62	0	69	70	64	0
71	72	66	0	73	71	65	0	74	72	69	0	71	73	75	0
73	73	67	0	76	74	68	0	75	76	70	0	72	74	76	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

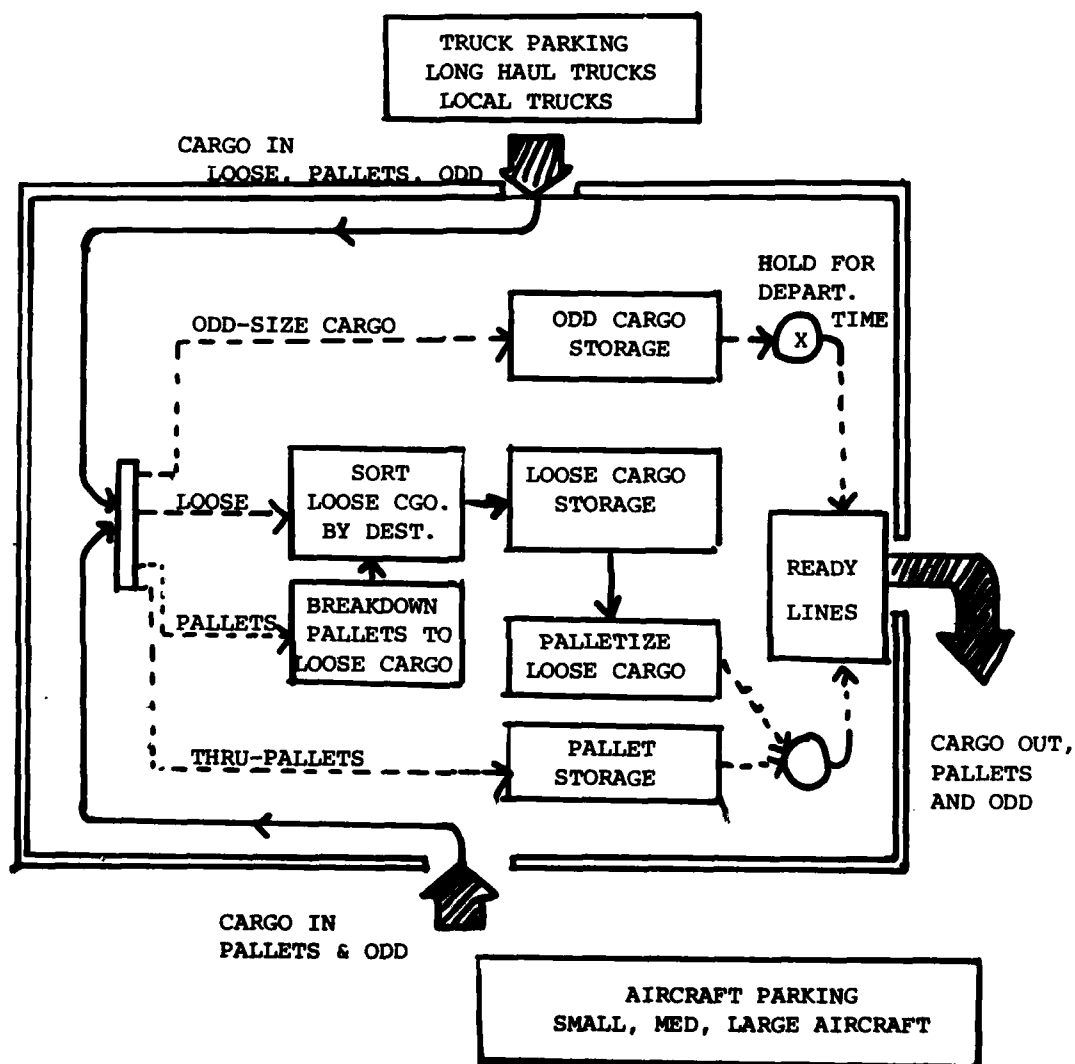
ROUTES SERVING THE FOLLOWING 0-0 PRS

1-2	1-3	1-4	1-5	2-1	2-3	2-4	2-5	3-1	3-2	3-4	3-5	4-1	4-2	4-3	4-5
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17	17	18	19	26	17	18	19	29	20	21	22	32	23	24	25
18	20	21	22	27	26	27	28	35	35	30	31	41	42	33	34
19	21	23	25	28	29	30	31	36	38	36	37	44	44	45	43
20	22	24	28	29	30	32	34	37	39	39	40	45	47	48	46
23	24	25	37	32	31	33	40	38	40	41	43	46	48	50	49
35	26	27	46	38	33	34	49	41	42	42	52	47	49	51	52
44	45	36	0	47	48	39	0	50	51	43	0	50	51	52	0
53	53	53	0	59	53	53	0	61	55	53	0	62	56	54	0
54	54	54	0	60	54	54	0	62	56	55	0	63	57	57	0
55	55	55	0	61	57	55	0	64	58	56	0	64	58	58	0
56	56	56	0	62	59	59	0	65	65	59	0	68	66	60	0
57	57	57	0	63	60	60	0	66	66	61	0	69	69	63	0
58	58	58	0	64	61	61	0	67	67	62	0	70	70	64	0
65	59	59	0	67	62	62	0	68	68	65	0	71	71	71	0
66	60	60	0	68	63	63	0	69	69	66	0	72	72	72	0
69	63	61	0	70	64	64	0	70	70	67	0	73	73	73	0
71	71	65	0	73	71	65	0	74	72	68	0	74	74	74	0
72	72	66	0	74	73	67	0	75	75	69	0	75	75	75	0
75	73	67	0	76	74	68	0	76	76	70	0	76	76	76	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

**APPENDIX III**

**SIMULATION**

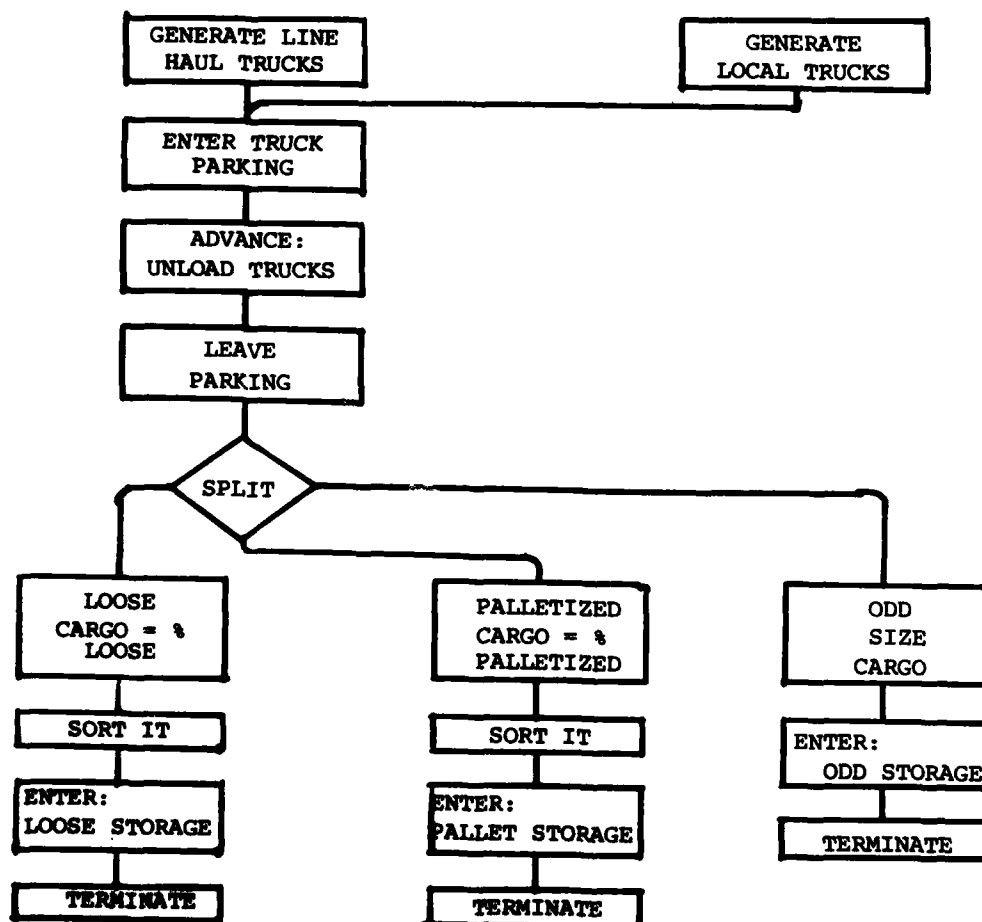
## 1. System Description:

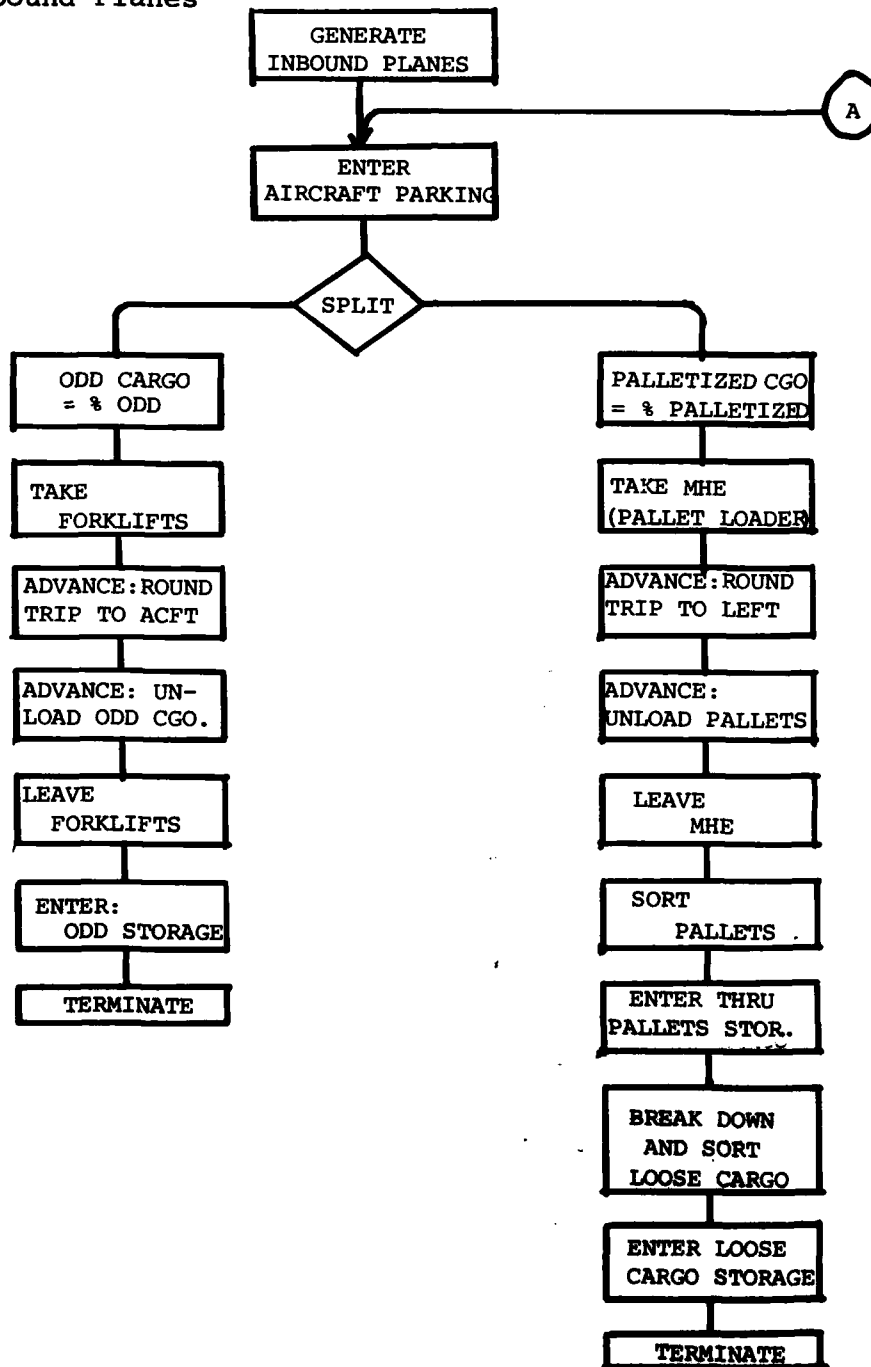




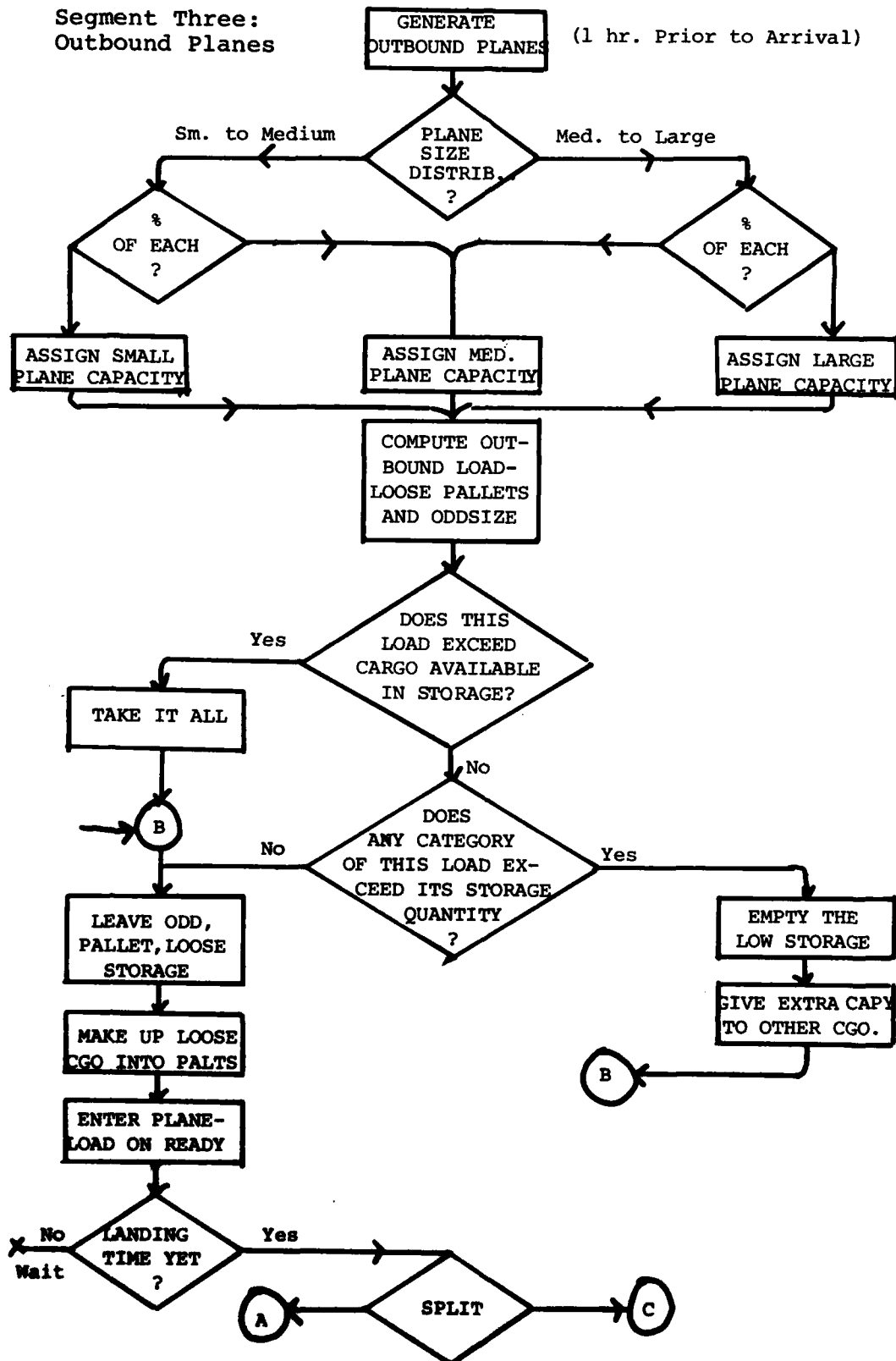
## 2. Simulation Flow Chart :

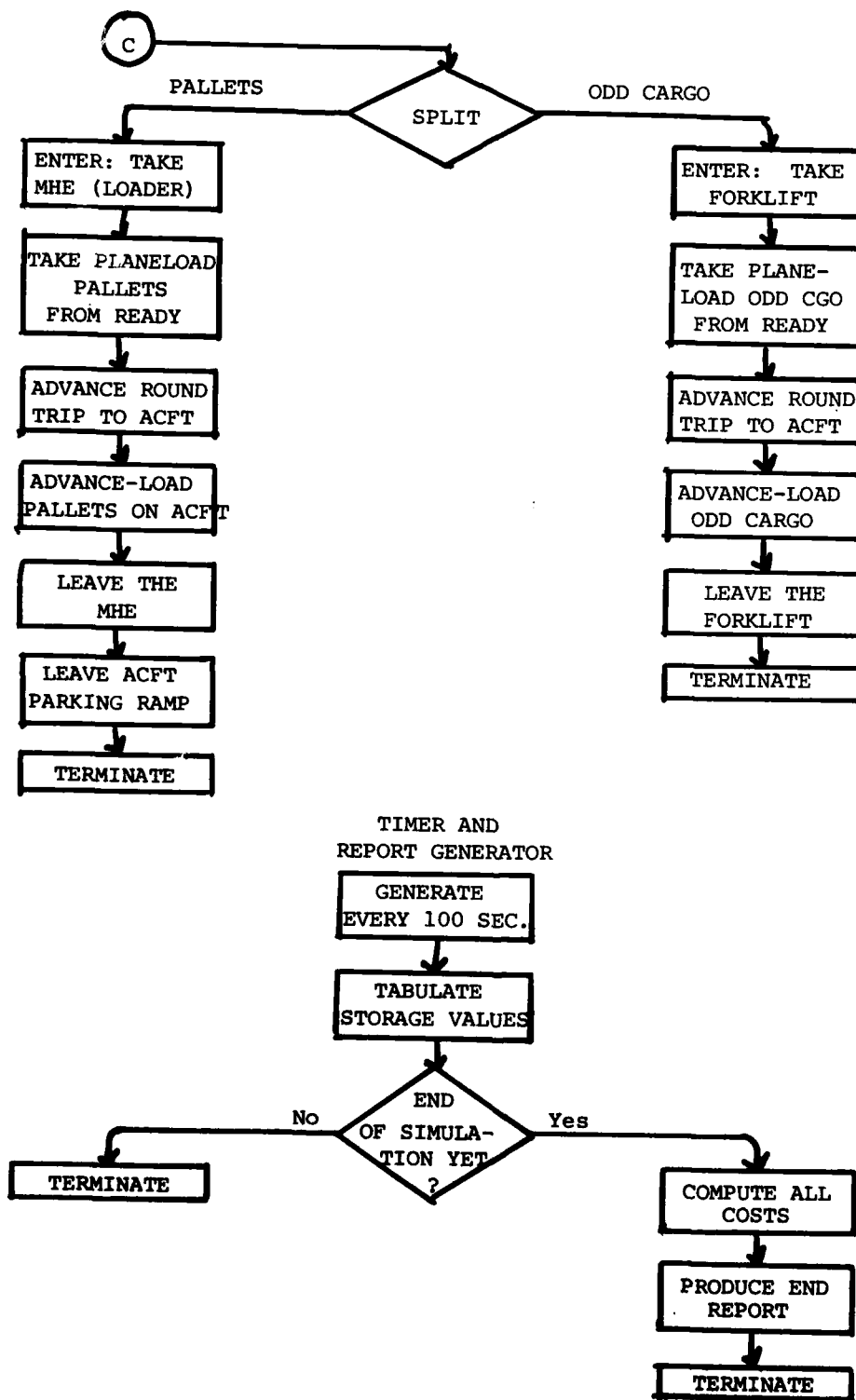
## Segment One: Inbound trucks



Segment Two  
Inbound Planes

Segment Three:  
Outbound Planes





## VARIABLE DESCRIPTION LIST

GPSS NAME	CURRENT VALUE	UNITS	MEANING
APCST	9	\$/day/sq mtr	cost of acft ramp (rent + construction)
DTARA	1440	sq mtrs	parking area used by 10 large trucks
DTCAP	91000	kg	avg load of 10 large trucks
FOCST	159	\$/day	cost of forklift, operator, supt crew
FORCP	4500	kg/forklift	cpcty of forklift for odd cargo
LOCDEX	100	/100	location index
LPCAP	60000	kg/plane	lg plane cpcty, @67% load factor
LSCST	8	\$/ton	storage cost for loose cargo
LSSST	300	\$/hr	cost of mech loose sorter, men, docum.
LTARA	700	sq mtrs	parking area used by 10 small trucks
LTCAP	3650	kg	avg load of 10 small trucks
MACST	480	\$/day	wages for pallet-building team
MHCST	277	\$/day	cost of material handler, load team
MHECP	18000	kg/loader	cpcty of pallet material hand equip
MPCAP	25000	kg/plane	med plane cpcty, @67% load factor
ODCST	38	\$/ton	cost of odd cargo storage
ODOFT	100	kg/sec	offload rate for odd size cargo
OTPSZ	5		selects combo of med & lg planes
PCTOD	250	% (pts/1000)	% of shipments which are odd size
PCTPA	750	% (pts/1000)	% of acft loads palletized
PCTPL	200	% (pts/1000)	% of truck shipments palletized
PCTSM	500	% (pts/1000)	% of outbound planes of smaller type
PKGSZ	1800	sq mtrs	ramp space reqd per 10,000 kg load
PLCST	23	\$/ton	cost of palletized cargo storage
PLOFT	24	sec/kg x 1000	time reqd to offload pallet from acft
PLTWT	2500	kg/pallet	avg wt of loaded pallet
PSCST	20	\$/hour	cost of palltzd cargo sorting & handling
RDCST	48	\$/10 tons	cost of storage space on ready line
SPCAP	10000	kg/plane	cpcty of sm plane @67% load factor
TNPXS	500	tons	amt cargo arrvng by air for air dept
TNTD	500	tons	amt cargo arrvng lg trk for air dept
TNTL	500	tons	amt cargo arrvng sm truck for air dept
TPCST	6	\$/day/sq mtr	cost of trk pkgng area (rent + cnstrctn)
XLOS	600	% (pts/1000)	% air-air xshppd palits to be resorted
XPAL	400	% (pts/1000)	% air-air xshppd palits as thru palits

```

*****FUNCTIONS*****
*
CAPA FUNCTION P4,N0
,XBPCAP/,XBMPCAP/,XBLPCAP/,XSPCAP/,XSMPCAP
CAPS FUNCTION P4,N0
,XBPCAP/,XBMPCAP/,XBLPCAP/,XSMPCAP/,XBLPCAP
CAPAV FUNCTION XBTPSZ,X5
,XBPCAP/,XBMPCAP/,XBLPCAP/,VBLCPAV/,VBLCPAV
XPOS FUNCTION RN2,C24
.007/.25,.204/.29,.222/.33,.335/.4,.509/.5,.609/.6,.915/.7,1.21/.75,1.35
.5,1.6/.64,1.65/.65,2.12/.9,2.31/.92,2.52/.94,2.61/.95,2.99/.96,3.2
.97/.97,3.98/.99,4.6/.995,5.2/.998,6.2/.999,7/.9998,8
TKSH FUNCTION F3,L2
.000/.200
SKRT FUNCTION B3PK0,C19
1000/31/5000,71/10000,100/20000,141/30000,173/40000,200/50000,223
60000,245/70000,264/80000,283/90000,300/100000,316/120000,346
140000,374/180000,400/190000,424/200000,447/250000,500/300000,545
*
*****VARIABLES*****
*
EMPTY FVARIABLE (P3'G'S+PLSTD)+(P4'G'S+LSSTD)+(P6'C'S+DDSTD)
DOENY FVARIABLE (3989/10000)*FNBSQRT/(20/3)+30
COST FVARIABLE VBLCOST1+VBLACST
COST1 FVARIABLE VBLPKST+VBLTOST+VBLUCST+VBLACST+VBLRDCST+VBLMHCST
CFT FVARIABLE XBLCOST*1000/VBLTNTCT
I4INP FVARIABLE 7200/(XBLTNPXS*1000/XBPCAP)
I4STP FVARIABLE 7200/((VBLTNTCT*1000)/FNBCAPAV)
I4TD FVARIABLE 14400/VBLTND
I4TL FVARIABLE 14400/VBLTL
LACST FVARIABLE ((2000+(XBLTNTL+XBLTND)*2)*XHLLOCX/100)
LCPAV FVARIABLE XBPCAP*XHBPCTSM/1000+XSMPCAP*(1000-XHBPCTSM)/1000
LDBL FVARIABLE P5*XHLXLS/1000
LSK FVARIABLE P2*((1000-XHBPCTOD)/1000)*((1000-XHBPCTPL)/1000)
LSSBK FVARIABLE P4/30+60
MACST FVARIABLE (100+303MAKUP*(ST3MAKUP/3600)*XH$MACST)*XHLLOCX/100
MNSP FVARIABLE P4/30+60
MHCST FVARIABLE VBLMHCST*(XHLLOCX/100)
MHCST1 FVARIABLE (SAIFGRK+1)*XBLRDCST+(SA3MHE+1)*XBLMHCST
NEBKK FVARIABLE (P3/XBLRDCP)+1
NINP FVARIABLE XBLTNPXS*1000/XBPCAP
NMM FVARIABLE (P3/XBLMHECP)+1
NNTP FVARIABLE VBLTNTCT*1000/FNBCAPAV
NTD FVARIABLE XBLTND*1000/XBLTDCAP
NTL FVARIABLE XBLTNTL+1000/XBLTDCAP
ODOFF FVARIABLE P2*XHBPCTOD/1000
ODOFF1 FVARIABLE P3/XH$ODOFF+120
OSK FVARIABLE P2*(XHBPCTOD/1000)
PAL3 FVARIABLE P3*XH$XPAL/1000
PKCST FVARIABLE VBLPKCST/260
PKCST1 FVARIABLE (349PK0+XH3APCST+343TKRKK*XH3IPCST)*(XHLLOCX/100)
PKCST2 FVARIABLE P2*XH3PKCST2/10000
PLCOFF FVARIABLE P2*XHBPCTPA/1000+60

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PLOTFT FVARIABLE P3*XH3PLOTFT/1000+60
PLDUR FVARIABLE (P3/XH3PLTWT)*60+60
PDR FVARIABLE P2*((1000-XH3PCTSD)/1000)*(XH3PCFPL/1000)
RDCST FVARIABLE SMREADY*XH3RDCST*(XH3LUCDX/100)/10000
SMSTL FVARIABLE SMPLSTL+SMDDSTL+SLSSSTL
SDCST FVARIABLE VSDCST+(SCPLSRT*STPLSRT*(XH3PSCST/3600)+30)
SJCST FVARIABLE (SCPLSRT*STPLSRT*(XH3LSSST/3600)+100)*XH3LUCDX/100
STCST FVARIABLE (VSTCST/10000+100+VINTST)*(XH3LUCDX/100)
STCST FVARIABLE SMPLSTL*XH3LST+SMPLSSTL*XH3LSCST+SMDDSTL*XH3DDCST
INTST FVARIABLE X3INTL+X3INTD+X3INPXS
DUPAV FVARIABLE X3MPCAP*XH3PCSM/1000+X3LPCAP*(1000-XH3PCTSM)/1000
X3TARA FVARIABLE P2-P3-P4-P5

```

\*\*\*\*\*TABLES\*\*\*\*\*

```

APKKS TABLE S4PKK,0,10000,20
FUPKS TABLE S4FUKK,0,1,20
LUCSE TABLE S4LSSST,0,100000,20
MHES TABLE S4MHES,0,1,20
JDD TABLE S4DDST,0,100000,20
PALS TABLE S4PLST,0,100000,20
TPKKS TABLE S4INPKK,0,500,10

```

\*\*\*\*\*SAVEVALUES\*\*\*\*\*

```

INITIAL X3INTL,500/X3INTD,500/X3INPXS,500/X3DTPS2,5
INITIAL XH3DTARA,1440/X3DTCAP,91000/XH3LTARA,700/X3LTCAP,3600
INITIAL X3LPCAP,10000/X3MPCAP,25000/X3LPCAP,6000
INITIAL XH3PCTSD,250/XH3PCFPL,200/XH3PQSZ,1800/X3MHESCP,18000
INITIAL X3FDRCP,400/XH3PCTPA,750/XH3PLOTFT,24/XH3XPAL,400
INITIAL XH3ALUS,600/XH3DDSTL,100/XH3PCTSM,100
INITIAL XH3PLTWT,2500/XH3LUCDX,100
INITIAL XH3APCST,9/XH3TPCST,6
INITIAL XH3PLCST,23/XH3LSCST,8/XH3DDCST,35
INITIAL XH3LSSST,300/XH3PSCST,20/XH3RDCST,45
INITIAL XH3MACST,480/X3FUCST,159/X3MHCSST,277

```

\*\*\*\*\*MAIN PROGRAM\*\*\*\*\*

\*\*\*\*\*SEGMENT ONE - INCOMING TRUCKS\*\*\*\*\*

```

1 GENERATE V3IATL,FN3XPDIS,,V3INTL,,,F GENERATE SMALL TRUCKS
2 ASSIGN 2,X3LTCAP ASSIGN SMALL TRUCK CAPACITY
3 ASSIGN 1,XH3LTARA PKG SIZE
4 ASSIGN 3,1 UNLOADING FUNCTION INPUT
5 LOT JOIN LARGE TRUCKS
6 GENERATE V3IATD,FN3XPDIS,,V3INTD,,,F GENERATE LARGE TRUCKS
7 ASSIGN 2,X3DTCAP ASSIGN LARGE TRUCK CAPACITY
8 ASSIGN 1,XH3DTARA PARKING SIZE
9 ASSIGN 3,2 UNLOADING FUNCTION INPUT
10 LOT ENTER TKPKK,P1 ENTER PARKING LOT
11 ADVANCE FN3TKOFF,120 UNLOAD THE TRUCK
12 LEAVE TKPKK,P1 LEAVE PARKING LOT
13 SPLIT 1,DDDSZ DDD SIZE CARGE IS GENERATED

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14	SPLIT	1,PALET	PALLETIZED CARGO IS GENERATED
15	ASSIGN	4,VBLSR	LOOSE CARGO IN SHIPMENT
16	ENTER	LSSRT	ENTER LOOSE CARGO SORTER
17	ADVANCE	VBLSSOR,15	SORT IT
18	LEAVE	LSSRT	LEAVE THE SORTER
19	ENTER	LSSTO,P2	ENTER LOOSE STORAGE BINS
20	TERMINATE		
21	PALLET ENTER	PLSRT	PALLETS ENTER SORTER
22	ASSIGN	3,VPLSR	PALLETIZED CARGO IN SHIPMENT-KG
23	ADVANCE	VPLSOR,30	SORT PALLETS
24	LEAVE	PLSRT	LEAVE SORTER
25	ENTER	PLSTO,P2	ENTER PALLET STORAGE (KG)
26	TERMINATE		
27	ODDSZ ENTER	ODSTO,VBLSR	ENTER ODD STORAGE (KG)
28	TERMINATE		

\*  
 \*SEGMENT TWO - INBOUND PLANES\*\*\*\*\*  
 \*

29	GENERATE	VBLAINP,,7200,VBNINP,,F	GENERATE INBOUND PLANES
30	ASSIGN	2,XLSPCAP	ASSIGN ITS CAPACITY
31	ASSIGN	1,V1PKGSZ	ASSIGN ITS PARKING SIZE
32	TAXIN ENTER	PKG,P1	
33	SPLIT	1,ODD	UNLOAD PALLETS + ODD CARGO SIMULT.
34	ASSIGN	3,V1PLOFF	TIME TO OFFLOAD PALLETS
35	ENTER	MHE,V1NMHE	USE A 'K LOADER'
36	ADVANCE	V1BOUNY,10	LOADER MAKES ROUND TRIP TO PLANE
37	ADVANCE	V1PLOFT,10	CREW OFFLOADS PALLETS
38	LEAVE	MHE,V1NMHE	CREW RELEASES LOADER
39	ENTER	PLSRT	PALLETS ENTER SORTER
40	ADVANCE	VPLSOR,30	ARE SORTED
41	LEAVE	PLSRT	LEAVE SORTER
42	ENTER	PLSTO,V1PALS	THRU PALLETS ARE STORED
43	ASSIGN	4,V1LOOSE	REMAINDER ARE BROKEN DOWN
44	ENTER	LSSRT	SORTING CREW ENGAGED
45	ADVANCE	VBLSSOR,15	PALLETS BECOME LOOSE CARGO + SORTED
46	LEAVE	LSSRT	RELEASE SORTER
47	ENTER	LSSTO,P4	STORE LOOSE CARGO (KG)
48	TERMINATE		
49	ODD ASSIGN	3,V1ODOFF	ODD CARGO TO BE OFFLOADED
50	ENTER	FORK,V1NFORK	TAKE FORKLIFTS
51	ADVANCE	V1BOUNY,10	ONE ROUND TRIP TO PLANE
52	ADVANCE	V1ODOFF,30	CREW OFFLOADS ODD CARGO
53	ENTER	ODSTO,P3	PLACES IT IN STORAGE
54	LEAVE	FORK,V1NFORK	RELEASES FORKLIFTS
55	TERMINATE		

\*  
 \*SEGMENT THREE - OUTBOUND PLANES\*\*\*\*\*  
 \*

56	GENERATE	V1IAOTP,,10800,V1NDTP,,F	START 1 HR PRIOR TO ARRIVAL
57	ASSIGN	4,X1DTPSZ	SM,MED,LG PLANES AS SPECIFIED
58	TRANSFER	X1DTPCTSM,,LOWER	OR A PERCENTAGE OF EACH
59	ASSIGN	2,FN1CAPB	CAPACITY ASSIGNED
60	ODD ASSIGN	RAMP	
61	LOWER ASSIGN	2,FN1CAPA	CAPACITY ASSIGNED
62	RAMP ASSIGN	1,V1PKGSZ	PARKING SIZE ASSIGNED



63		ASSIGN	3,V&PLOFF	KG PALLETIZED CGO FOR UNLOAD
64		ASSIGN	4,V&LOOSE	KG LOOSE
65		ASSIGN	6,V&LOOFF	KG ODD-SIZE
66		ASSIGN	3,V&PALS	KG THRU PALLETS
67		TEST GE	V&SMSTO,P2,CLEAN	WILL THIS EMPTY ALL STG
68		TEST E	EV&EMPTY,0,NOPAL	NO..WILL ANY STORAGE BE EMPTIED
69	W&SOT	LEAVE	LSSTO,P4	NO..THEN RETRIEVE LOOSE CGO
70		LEAVE	PLSTO,P3	RETRIEVE PLTS FROM STORAGE
71		LEAVE	ODSTO,P6	RETRIEVE ODD CARGO
72		ENTER	MAKUP	ENTER PALLET MAKUP AREA
73		ADVANCE	V&MAKUP,15	BUILD THE PALLETS
74		LEAVE	MAKUP	LEAVE MAKUP AREA
75		ENTER	READY,P3	PLACE THRU PALLETS
76		ENTER	READY,P4	NEW PALLETS,
77		ENTER	READY,P6	AND ODD CARGO ON READY LINE.
78		TEST GE	M,000	WAIT UNTIL LOADING TIME
79		SPLIT	1,TAXIN	TAXI IN FOR OFFLOAD/UNLOAD
80		GOTO	LOOP	GO TO BEGIN LOADING
* EMPTY STORAGE SUB-SEGMENT				
81	NOPAL	TEST G	P3,S&PLSTO,NOLDS	WILL THE PALLET STO BE EMPTIED
82		ASSIGN	3,S&PLSTO	THEN TAKE IT ALL
83		TEST G	S&LSSTO,S&ODSTO,ODDX	WHICH OTHER STO HAS MORE LEFT
84		ASSIGN	4+,V&XTRA	TAKE EXTRA LOOSE CARGO
85		GOTO	NOLDS	
86	ODDX	ASSIGN	6+,V&XTRA	TAKE EXTRA ODD CARGO
87	NOLDS	TEST G	P4,S&LSSTO,NOLDS	WILL LOOSE STO BE EMPTIED
88		ASSIGN	4,S&LSSTO	TAKE IT ALL
89		TEST G	S&PLSTO,S&ODSTO,ODDX2	WHICH OTHER STO HAS MORE LEFT
90		ASSIGN	3+,V&XTRA	TAKE EXTRA PALLETIZED CARGO
91		GOTO	NOLDS	
92	ODDX2	ASSIGN	6+,V&XTRA	TAKE EXTRA ODD CARGO
93	NOLDS	TEST G	P6,S&ODSTO,W&SOT	WILL THIS EMPTY ODD STO
94		ASSIGN	6,S&ODSTO	TAKE IT ALL
95		TEST G	S&PLSTO,S&LSSTO,LSSX	WHICH OTHER STO HAS MORE LEFT
96		ASSIGN	3+,V&XTRA	TAKE EXTRA PALLETS
97		GOTO	W&SOT	GO TO PREPARE THE LOAD
98	LSSX	ASSIGN	4+,V&XTRA	TAKE EXTRA LOOSE CARGO
99		GOTO	W&SOT	PREPARE THE LOAD
100	CLEAN	ASSIGN	3,S&PLSTO	IF ALL STORAGES WILL BE EMPTIED,
101		ASSIGN	4,S&LSSTO	TAKE IT ALL AND DEPART
102		ASSIGN	6,S&ODSTO	BELOW CAPACITY
103		GOTO	W&SOT	PREPARE THE LOAD
* PLANE NOW LANDS, PARKS, IS OFFLOADED, RETURNS TO BE UNLOADED				
104	LOOP	SPLIT	1,ODDUP	LOAD PALLETS AND ODD CGO SIMULT.
105		ENTER	MHE,V&NMHE	TAKE A K LOADER
106		ADVANCE	V&BONY,10	ONE ROUND TRIP TO PLANE SIDE
107		LEAVE	READY,P3	GET PALLETS FROM READY LINE
108		LEAVE	READY,P4	GET NEW PALLETS FROM READY LINE
109		ADVANCE	V&PLOFF,30	LOAD THE PLANE
110		LEAVE	MHE,V&NMHE	RELEASE THE K LOADER
111		LEAVE	PKG,P1	PLANE TAXIES OUT
112		TERMINATE		
113	ODDUP	ASSIGN	3,P6	KG OF ODD CARGO
114		ENTER	FURK,V&NFORK	TAKE A FORKLIFT
115		ADVANCE	V&BONY,10	MAKE A ROUND TRIP TO PLANESIDE

116	LEAVE	READY, PB	TAKE ODD CARGO FROM READY
117	ADVANCE	V\$DDOFT, 30	LOAD ODD CARGO
118	LEAVE	FORK, V\$NFORK	RELEASE FORKLIFT
119	TERMINATE		

\*  
\*TIMER AND REPORT GENERATOR SEGMENT\*\*\*\*\*  
\*

120	GENERATE	100, 100, 216	SAMPLE EVERY 100 SECONDS
121	TABULATE	FORKS	NUMBER FORKLIFTS IN USE
122	TABULATE	MHES	NUMBER K LOADERS IN USE
123	TABULATE	LOOSE	AMT LOOSE STORAGE IN USE
124	TABULATE	PALTS	AMT PALLET STORAGE IN USE
125	TABULATE	ODD	AMT ODD STORAGE IN USE
126	TABULATE	TPRKG	AMT OF TRUCK PKG IN USE
127	TABULATE	APRKG	AMT ACFT PKG IN USE
128	SAVEVALUE	LOOP+, 1, H	INCREMENT COUNTER
129	TEST GO	74, LOOP, 216, HALT	IS THIS THE LAST SAMPLE
130	SAVEVALUE	COST, V\$COST	YES, CALCULATE TOTAL COST AND
131	SAVEVALUE	PKCS, V\$PKCS	COST OF PARKING
132	SAVEVALUE	STCS, V\$STCS	STORAGE,
133	SAVEVALUE	SDCS, V\$SDCS	SORTING,
134	SAVEVALUE	MACS, V\$MACS	CONTAINERIZING,
135	SAVEVALUE	RDCS, V\$RDCS	READY LINE,
136	SAVEVALUE	MHCS, V\$MHCS	MATERIALS HANDLING,
137	SAVEVALUE	LACS, V\$LACS	LABOR,
138	SAVEVALUE	CPT, V\$CPT	AND COST PER TON.

REPORT

MSV TITLE ,HALFWORD SAVEVALUES

FSV TITLE ,FULLWORD SAVEVALUES

2	TEXT	COST OF PARKING	'X\$PKCS,2/0LXXXXXXXX'
2	TEXT	COST OF CARGO STORAGE	'X\$STCS,2/0LXXXXXXXX'
2	TEXT	COST OF CARGO SORTING	'X\$SDCS,2/0LXXXXXXXX'
2	TEXT	COST OF CONTAINERIZING	'X\$MACS,2/0LXXXXXXXX'
2	TEXT	COST OF READY AREA	'X\$RDCS,2/0LXXXXXXXX'
2	TEXT	COST OF MATERIALS HANDLING	'X\$MHCS,2/0LXXXXXXXX'
2	TEXT	COST OF LABOR	'X\$LACS,2/0LXXXXXXXX'
	SPACE	1	
2	TEXT	TOTAL COST OF THIS OPERATION IS	'X\$COST,2/0LXXXXXXXX'
	SPACE	2	
2	TEXT	COST PER TON	'X\$CPT,2/3LXXXX.XX'
139	HALT	TERMINATE	1

\*  
\*\*\*\*\*CONTROL CARDS\*\*\*\*\*  
\*

START 216

#### VITA

Peter W. Russo was born in Brooklyn, New York on 4 March 1949. He attended Manhattan College, Bronx, New York, while working as a freight conductor for the Penn Central Railroad.

Upon receiving his bachelor's degree in Civil Engineering in 1971, he entered the U. S. Air Force pilot training program. Captain Russo has since logged nearly 3,000 hours flying the Lockheed C-130 Hercules transport aircraft on various assignments world-wide. Upon completion of these Air Force sponsored studies at Northwestern, he will be assigned to the Air Terminal Operations Center at RAF Mildenhall, United Kingdom.